TOWARDS A GREEN AND RESILIENT THAILAND

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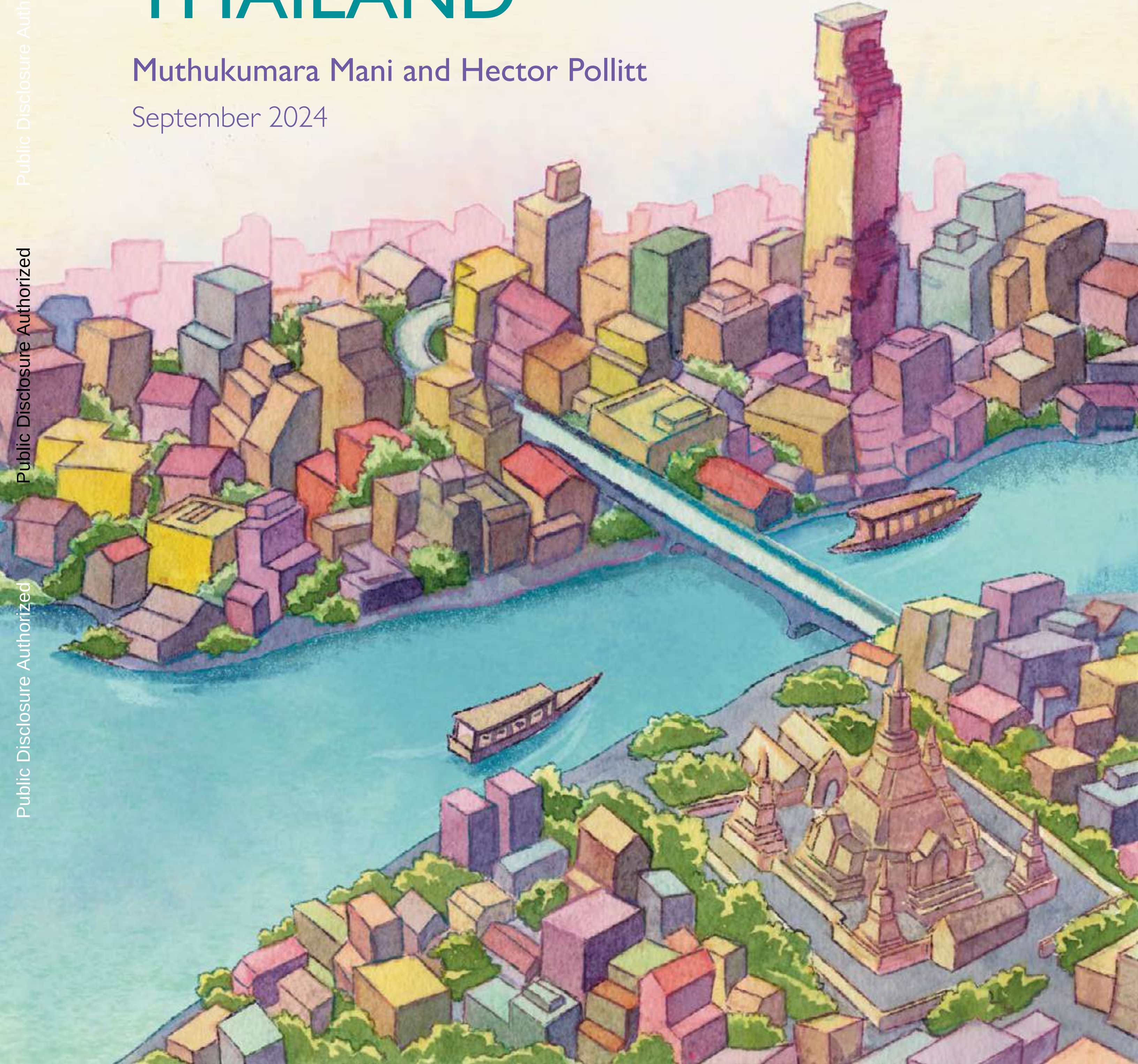
Muthukumara Mani and Hector Pollitt

September 2024



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Acronyms & Abbreviations

ANS	Adjusted Net Savings
BCG	Bio-Circular-Green
CCDR	Country Climate and Development Reports
CET	Constant Elasticity of Transformation
CGE	Computable General Equilibrium
CLUE	Conversion of Land Use and its Effects
Dyna-CLUE	Dynamic CLUE
EIA	Environmental Impact Assessments
E3M	E3-Thailand Model
EV	Electric vehicles
ES	Ecosystem services
EPR	Extended producer responsibility
ESM	Ecosystem Services Modeling
FDI	Foreign direct investment
FTT	Future Technology Transformations
GAR	Global Assessment Report
GDP	Gross Domestic Product
GHG	Greenhouse gases
GHS	Global Human Settlement
GIS	Geographic Information Systems
GNI	Gorss National Income
IEEM	Integrated Economic-Environmental Model
IO	Input-output
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
IPPU	Industrial processes and product use
LULC	Land Use Land cover
LT-LEDS	Long-Term Low Greenhouse Gas Emission Development Strategy
NDC	Nationally Determined Contribution
RCP	Relative Concentration Pathway
SAM	Social Accounting Matrix
SEEA	United Nations System of Environmental-Economic Accounting
SLR	Sea level rise
SME	Small- and medium-sized enterprises
THB	Thai Baht
UNFCCC	UN Framework Convention on Climate Change
WBGT	Wet-Bulb Globe Temperature

EXECUTIVE SUMMARY

INTRODUCTION

Thailand has made significant progress in its economic development, transitioning from a low-income to an upper-middle-income country. Going forward, the country is facing persistent challenges, including a deceleration in economic growth, climate vulnerability, and environmental degradation.

The government has outlined its vision for a Bio-Circular-Green (BCG) economy to create a sustainable and competitive economic landscape to tackle these challenges. Introduced in 2021, the BCG model seeks to combine Thailand's biological and cultural diversity with technological innovation to create a new growth paradigm.

Mounting evidence shows that Thailand is extremely vulnerable to climate change, with rising sea levels, extreme weather events, and changing precipitation patterns posing significant risks to both urban and rural areas. The nation is vulnerable to a range of natural hazards, including floods, landslides, tropical cyclones, droughts, and coastal erosion. An uneven distribution of climate impacts across the country highlights the need for targeted interventions to address specific vulnerabilities. For example, Thailand's population is predominantly concentrated in urban areas, with rapid urbanization increasing the vulnerability of densely populated concentrations to climate-related risks, particularly floods. Lower-income households, often residing in hazard-prone areas, face greater challenges due to limited access to essential services. The country's vital agricultural sector is also significantly threatened by altered rainfall patterns and temperature extremes, jeopardizing crop production.

The depletion of natural resources, along with environmental degradation, further exacerbate the challenges faced by Thailand. Forest coverage is decreasing, and built-up assets, particularly in major cities, are susceptible to the impacts of climate hazards. The country's rich natural capital plays a crucial role in supporting local livelihoods, and the loss of biodiversity and ecosystem functions poses significant risks to communities and key economic sectors. For example, the total loss of land due to coastal erosion is estimated at two square kilometers per year, with a value equal to .04 percent of gross domestic product (GDP). Cities and economic activities in coastal areas are especially vulnerable to coastal erosion.

Given the increasing climate challenges, this report updates Thailand's BCG model for current circumstances. We call it BCG+. The report uses advanced modeling and other cutting-edge analytics to take a whole-of-the-economy perspective so that BCG+ is assessed within the context of broader economic development. Beyond environmental concerns, Thailand's economic risks, tied to global trends and its reliance on tourism, necessitate a revised development model. The BCG+ economy could mitigate these exposures by reducing reliance on global commodity prices and enhancing economic resilience. By integrating measures on climate resilience, sustainable resource management, and inclusivity in its development strategy, Thailand can work towards achieving its vision of a BCG economy.

THE BCG+ TRANSITION

Transitioning to a BCG+ economy requires contributions from all sectors of society, with a focus on sector-specific characteristics. Whole-economy policies such as carbon taxes need to consider technological nuances for effectiveness. Circular production poses additional challenges due to multiple inputs and outputs in the business model. Coordination between the public and private sectors is imperative. The public sector must initiate change, finding financing solutions for actions like climate adaptation, potentially through an economy wide carbon tax. Simultaneously, private companies bear responsibility for improving efficiency, fostering innovation, and aligning product designs with bio-circular goals.

The transition offers macro-level opportunities, showcasing potential benefits like increased economic welfare, higher incomes, and enhanced employment levels. Technological advancements and undiscovered productivity avenues underpin these opportunities, positioning the BCG+ economy as a driver for economic development. Crucially, this shift safeguards Thailand from future climate and economic risks while preserving natural capital for sustainable growth.

METHODOLOGY

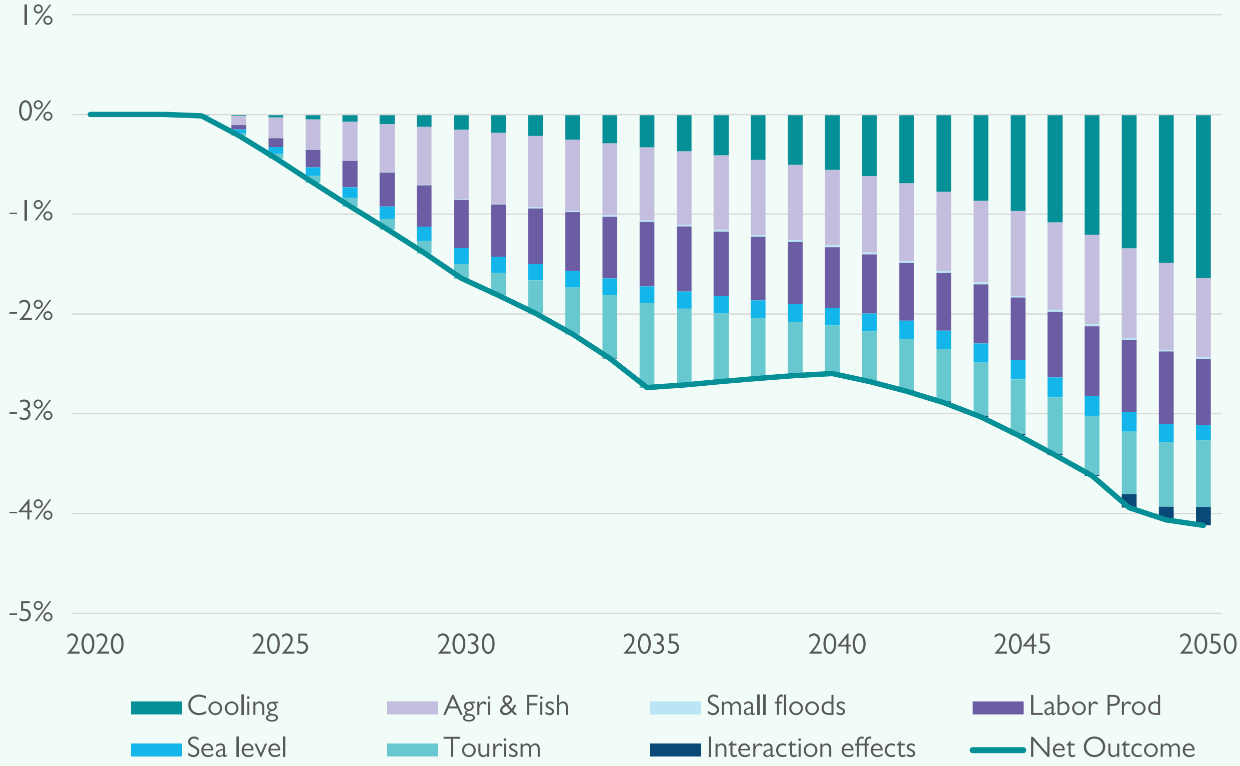
Macro-level and sectoral modeling tools can identify the whole-economy effects of the BCG+ challenge. Although there is considerable uncertainty about the future economic impacts of climate change, modeling tools can help to identify which parts of the economy are most vulnerable, both directly and indirectly. Similarly, for climate change mitigation and other aspects of BCG+, models can be useful in planning future policy. It is important that models are applied appropriately, especially given data limitations related to climate change and potential climate change adaptation measures.

The report applied a suite of advanced modeling tools. The broad coverage of the BCG+ development model means that a variety of quantitative tools is required to assess impacts. The report uses a combination of macro-econometric, input-output, and technology diffusion modeling. It also applies a Computable General Equilibrium model that is linked to high-resolution spatial Land Use Land Cover (LULC) analysis and an ecosystem services model. In all cases, model results are compared to a "business-as-usual" baseline scenario to identify the climate and policy shocks.

KEY FINDINGS

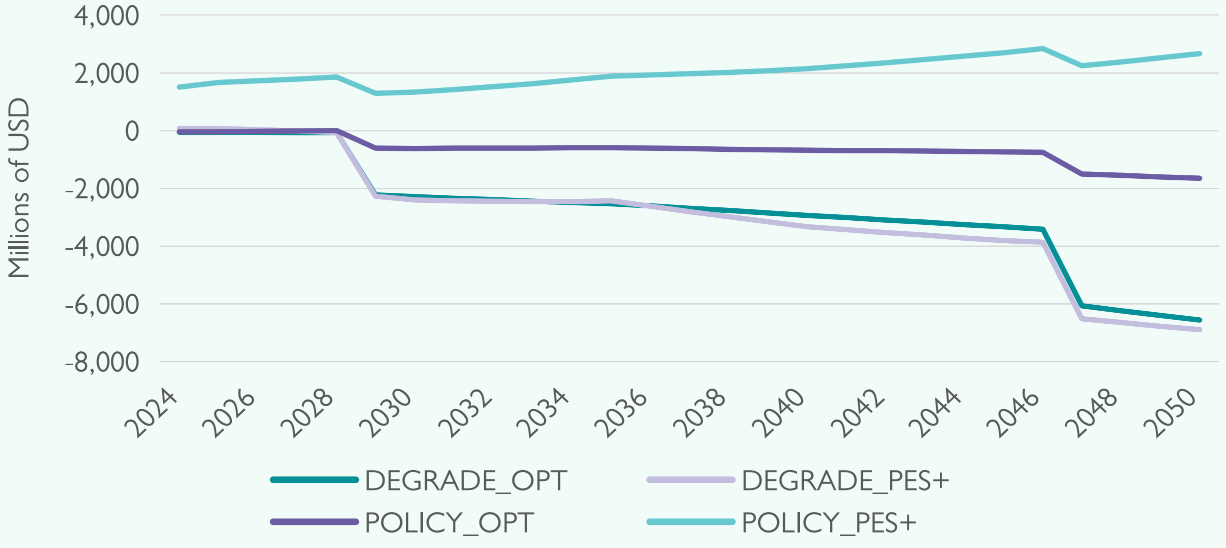
The report underscores that Thailand's agriculture and fishing sectors are particularly susceptible to climate change, a vulnerability heightened by the country's substantial local fishing and shrimp farming industries. This susceptibility is critical as many low-income households rely on these sectors for their livelihoods. The potential impacts are severe: agriculture could experience production losses ranging from $2.9 billion to $5.4 billion, while up to $26.2 billion of fishing production value is at risk. Furthermore, heat stress will severely impact ocean ecosystems, leading to significant fishing losses across all climate scenarios. Additionally, climate change is already reducing productivity in outdoor labor sectors such as agriculture and construction, with potential productivity losses doubling by 2050. Although indoor labor productivity, supported by air conditioning, will face less of an impact, the cost of installing and maintaining cooling systems could reach $11 billion to $17 billion annually by 2050 (Figure ES1).

Figure ES1. Impact of different categories of climate damages on GDP



The report also explores the severe economic implications of approaching ecological tipping points, such as excessive deforestation and flooding. It compares two scenarios: DEGRADE, which involves ongoing deforestation and increased flooding, and POLICY, which includes proactive measures to mitigate these effects. Thailand's forest cover has already declined by 12% since 2000, and continued deforestation could lead to substantial ecological and economic losses. Effective policy interventions, such as halting deforestation and promoting reforestation, could mitigate these impacts. Without action, Thailand might face up to $553 billion in GDP losses by 2050. However, strategic policies could reduce these losses by 68% and potentially enhance cumulative wealth by $54 billion through reforestation and afforestation initiatives.

Figure ES2. Impact of policy interventions to safeguard wealth

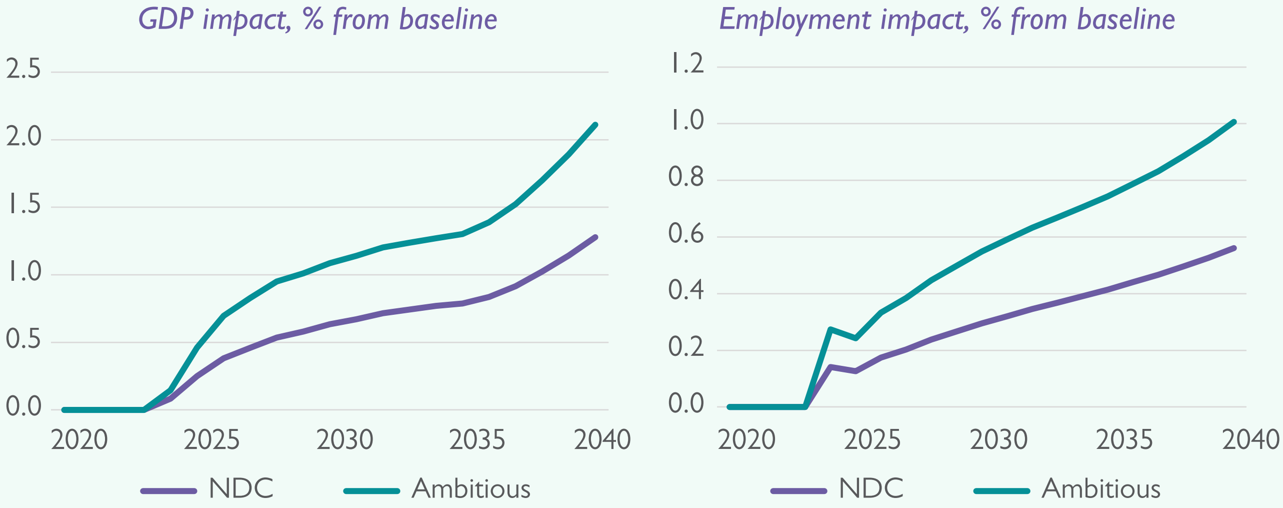


Source: IEEM+ESM results. Note: scenario names that terminate in OPT consider the RCP4.5 pathway while those that terminate in PES use the RCP8.5 pathway projection.

The report highlights that climate change could significantly affect Thailand's economy, especially through increased flood damage and sea-level rise. For instance, the economic impact of a major flood in 2030 could decrease GDP by up to four percentage points. Additionally, costs related to coastal erosion and sea-level rise are projected to increase by approximately $6 billion over time. Addressing these risks will require comprehensive climate adaptation and mitigation strategies. This includes implementing carbon pricing mechanisms and accelerating the transition to electric vehicles (EVs). Carbon pricing can incentivize emission reductions and potentially boost GDP and employment if the revenues are used to lower other taxes (Figure ES3). However, adaptation costs could reach at least 1.6 percent of GDP by the 2030s, with the government likely covering most of these expenses. Power sector reforms, aimed at reducing emissions, may reduce carbon tax revenues, while fuel excise duties could initially increase but decrease with the transition to EVs.

A successful transition to a circular economy by 2030 could lead to a 1.0 percent increase in GDP and the creation of 160,000 jobs. This shift, driven by improved waste management practices and reduced reliance on virgin resources, offers substantial economic benefits. For example, reducing food waste could boost agricultural and food exports, and transforming waste into new materials could increase value added in advanced manufacturing and service sectors. However, the success of these measures will depend on the availability of skilled workers and the need for sector-specific assessments to ensure effective implementation.

Figure ES3. GDP and Employment impact of carbon taxes



FOCUS AREAS AND RECOMMENDATIONS

While all actions in this report are valuable, some are more urgent due to their path dependencies and the opportunities they create, such as governance enhancements leading to larger adaptation investments. The report categorizes actions into short-term (by 2030), medium-term (by 2040), and long-term priorities (beyond 2040-50). Certain measures, including those improving economic and fiscal management, governance, and job creation, will advance both climate and development goals.

Adaptation is a major focus. Thailand should prioritize planning and preparing for climate impacts like flooding. Implementing early warning systems, improving access to essential services for lower-income households, investing in climate-resilient infrastructure, and enforcing land use policies are crucial. Measures such as sustainable land use and green infrastructure can reduce flood damage and other climate risks, potentially lowering the GDP impact of major floods in 2030 by four percentage points. Adapting existing infrastructure and addressing other climate impacts, like reduced fish catches and heat stress, are more challenging. Overall adaptation expenses could be at least 1.6 percent of GDP.

The study's modeling informs key policy recommendations for climate adaptation in Thailand. These recommendations, detailed in Table ES1, are vital for enhancing resilience and mitigating climate impacts. Integrating these strategies into Thailand's adaptation efforts will build a more resilient economy, improve quality of life, and ensure a sustainable future. Investing in adaptation protects communities and infrastructure, reduces disaster-related losses, and enhances productivity in key sectors.

Mitigating climate change is also crucial. Thailand faces challenges in reducing its carbon footprint and achieving carbon neutrality by 2050 amid rapid urbanization and fossil fuel reliance. Key strategies include comprehensive policies, renewable energy investments, and clean technologies.

Transitioning to renewable energy, improving energy efficiency, and promoting electric vehicles are essential. Carbon pricing and electric vehicle adoption will help reduce emissions. Success requires strong policies, collaboration between government and industry, and public awareness. Key recommendations for mitigation strategies are outlined in Table ES2.

The roles of the public and private sectors in achieving carbon neutrality are distinct yet interconnected. The public sector must craft and enforce policies, invest in renewable infrastructure, and raise awareness. The private sector should implement these policies through innovation and investments in clean technologies. Effective collaboration between government and industry is essential for a unified approach to carbon mitigation.

Embracing a circular economy is vital, particularly for addressing plastic waste in the Chao Phraya River. Transitioning to this model reduces plastic consumption, promotes recycling, and minimizes waste. Policies like extended producer responsibility and eco-design standards can curb plastic pollution. Investing in waste management infrastructure and recycling technology will enable efficient waste recovery. The public sector should set regulatory frameworks and invest in infrastructure, while the private sector should drive innovation and improve product design. Key recommendations for transitioning to a circular economy are detailed in Table ES3.

Table ES1. Priority Adaptation Actions

Action	Description	Urgency	Co-benefits	Feasibility
Implement flood management strategies	Given the significant projected impact of floods, Thailand must prioritize comprehensive flood management strategies to reduce the vulnerability of communities and infrastructure. Key measures include investing in flood control infrastructure like levees and flood barriers, implementing nature-based solutions such as wetland restoration and floodplain zoning, and strategically locating new infrastructure away from flood-prone areas. Enhancing resilience through improved drainage systems and promoting green infrastructure can further mitigate the adverse impacts of floods. (Ministry of Natural Resources and Environment, Ministry of Interior, Urban Local Bodies and Communities)	S	3	L
Develop early warning systems and enforce building regulations	Early warning systems are vital for preparedness and reducing the risk of loss during extreme weather events. Thailand should invest in advanced technologies and community engagement for these systems. Enforcing building regulations to ensure structures can withstand and are elevated above flood levels is essential. Strategic planning	S	3	L

Action	Description	Urgency	Co-benefits	Feasibility
	and zoning in flood-prone areas, guided by risk assessments, can minimize exposure, and promote sustainable development. (Ministry of Natural Resources and Environment, Ministry of Interior, Ministry of Agriculture, Local Government Units and Community Organizations)	S	3	L
Enhance coastal resilience	With the increasing threat of sea-level rise and coastal erosion, Thailand should enhance coastal resilience. This includes implementing nature-based solutions like mangrove restoration and beach nourishment and investing in hard infrastructure like seawalls and breakwaters. Developing coastal zone management plans that integrate climate considerations and involve local communities is crucial for sustainable coastal adaptation. (Department of Marine and Coastal Resources, Department of National Parks, Wildlife and Plant Conservation. Local Community Groups)	M	2	HL
Promote climate-smart agriculture	Climate change poses significant risks to Thailand's agriculture, crucial for food security and livelihoods. To build resilience, Thailand should promote climate-smart practices like crop diversification, water-efficient irrigation, and soil conservation. Providing farmers with access to climate information and extension services will help them to adapt and minimize crop losses. (Ministry of Agriculture and Cooperatives, Ministry of Natural Resources and Environment, Local Government Units and Community Organizations, Research Institutions and Academia)	M	1	L
Strengthen urban resilience	As urbanization accelerates, cities in Thailand face increased climate-related risks like heatwaves, urban flooding, and infrastructure damage. Investing in green infrastructure, such as parks and green roofs, can mitigate the urban heat island effect and reduce flood risk. Integrating climate considerations into urban planning and design, including climate-responsive building codes and sustainable transport systems, will enhance urban resilience and promote sustainable development. (Ministry of Interior, Ministry of Natural Resources and	L	2	LL

Action	Description	Urgency	Co-benefits	Feasibility
	Environment, Ministry of Digital Economy and Society, Local Government Units and City Planning Authorities, Private Sector and Industry)	L	2	LL
Enhance community-based adaptation	Recognizing the importance of local knowledge and community participation, Thailand should prioritize community-based adaptation approaches. Empowering local communities to implement tailored adaptation measures will enhance grassroots resilience. Supporting community-led initiatives, such as climate-resilient agriculture and disaster risk reduction activities, can build social cohesion and strengthen adaptive capacity. (Ministry of Agriculture and Cooperatives, Ministry of Natural Resources and Environment, Local Government Units and Community Organizations)	L	2	L
Invest in climate-resilient infrastructure	Climate-proofing infrastructure investments is essential for reducing vulnerability to climate change impacts. Thailand should integrate climate considerations into infrastructure planning, design, and maintenance across sectors like transportation, energy, and water management. This includes incorporating climate risk assessments, designing infrastructure to withstand extreme weather, and ensuring robust maintenance and monitoring systems. (Ministry of Transport, Ministry of Energy, Ministry of Interior. Local Government Units and Municipal Authorities, Private Sector and Industry)	M	2	L

Table ES2. Priority Mitigation Actions

Action	Description	Urgency	Co-benefits	Feasibility
Implement carbon pricing mechanisms	Introducing carbon pricing mechanisms, such as a carbon tax or emissions trading scheme, in Thailand can incentivize businesses to reduce carbon emissions. These mechanisms encourage cleaner technologies and practices, leading to reduced emissions. Revenue from carbon pricing can be reinvested in climate mitigation and adaptation efforts, enhancing Thailand's resilience to climate change.	S	2	HL

Action	Description	Urgency	Co-benefits	Feasibility
	(Ministry of Finance, Ministry of Environment and Natural Resources, Ministry of Industry, Ministry of Energy, Ministry of Agriculture and Cooperatives, Private Sector and Industry)	S	2	HL
Power sector reforms	The Government of Thailand should prioritize power sector reforms to enhance the effectiveness of carbon taxes. By aligning energy pricing with carbon reduction goals, these reforms would encourage investment in cleaner technologies and support a smoother transition to a low-carbon economy. (Ministry of Energy, Electricity Generating Authority of Thailand, Ministry of Finance, Energy Regulatory Commission, Department of Alternative Energy, Development and Efficiency, Private Sector and Industry, International Organizations and Development Partners)	S	3	L
Utilize carbon tax revenues to support other climate policy	The revenue generated from carbon taxes could be channeled into a dedicated climate fund, supporting other critical climate policies and initiatives, further accelerating the country's transition to a low-carbon climate resilient economy. (Ministry of Finance, Ministry of Energy, Office of the National Economic and Social Development Council. Climate Change Department, Ministry of Environment and Natural Resources, Energy Regulatory Commission)	S	3	HL
Collaborate for electric vehicle transition	Collaborating with international organizations and private sector partners can accelerate Thailand’s transition to electric vehicles (EVs). By sharing knowledge, expertise, and resources, Thailand can address barriers to EV adoption, such as high upfront costs and limited charging infrastructure. These partnerships can also foster domestic EV manufacturing capabilities, creating new opportunities for economic growth and innovation. (Automobile Manufacturers, Charging Infrastructure Providers, Energy Companies, Ministry of Energy, Ministry of Transport, Thailand Board of Investment)	M	2	L

Action	Description	Urgency	Co-benefits	Feasibility
Implement a comprehensive EV policy package	Thailand can promote widespread EV adoption through a comprehensive policy package. This could include incentives for EV purchases, subsidies for charging infrastructure, and tax breaks for manufacturers. By addressing both supply and demand-side barriers, Thailand can create a supportive environment for EV uptake, reduce GHG emissions from transportation, and improve urban air quality. (Ministry of Energy, Ministry of Transport, Department of Land Transport Electricity Generating Authority of Thailand, Thailand Board of Investment, Ministry of Finance, National Science and Technology Development Agency. Office of the National Economic and Social Development Council)	M	2	L
Implement afforestation and forest restoration measures	Thailand can mitigate climate change and protect ecosystems by implementing afforestation and forest restoration measures. Restoring degraded forests and expanding green cover will sequester carbon dioxide, enhance biodiversity, and provide economic benefits such as job creation in forestry and opportunities for ecotourism. These measures are essential for Thailand's long-term climate resilience and sustainability. (Ministry of Natural Resources and Environment, Department of National Parks, Wildlife and Plant Conservation, Royal Forest Department, Department of Land Development, Ministry of Agriculture and Cooperatives, Office of the National Economic and Social Development Council, Local Government Units and Municipal Authorities, Private Sector and Non-Governmental Organizations)	L	2	L
Enhancing Energy Efficiency	Improving energy efficiency in Thailand is essential for reducing consumption and greenhouse gas emissions. Measures include adopting strict efficiency standards, promoting energy-efficient building designs, and using smart grid technologies. Incentives for energy audits and savings technologies, along with public awareness campaigns and training, will	M	2	L

Action	Description	Urgency	Co-benefits	Feasibility
	support a transition to a greener economy and lower overall energy demand. (Ministry of Energy, Department of Alternative Energy Development and Efficiency, Energy Regulatory Commission, Ministry of Interior, Office of the National Economic and Social Development Council, Thai Green Building Institute, Local Government Units and Municipal Authorities, Private Sector and Industry Associations)			

Table ES3. Priority Circular Economy Actions

Action	Description	Urgency	Co-benefits	Feasibility
Policy Framework for Circular Economy	The Thai government should create a comprehensive policy framework for a circular economy, including regulations, incentives, and guidelines to promote sustainable design, resource efficiency, and waste reduction. Setting clear targets and timelines will guide and hold stakeholders accountable across sectors. (Ministry of Natural Resources and Environment, Department of Environmental Quality Promotion, Ministry of Industry, Office of the National Economic and Social Development Council, Department of Industrial Works, Thailand Board of Investment, Local Government Units and Municipal Authorities)	M	2	HL
Support Innovation and Technology	Thailand should leverage innovation and technology to advance the circular economy. Investing in research and development will help scale up technologies for recycling, remanufacturing, and resource recovery. Embracing digital technologies and data analytics can optimize resource use and support circular business models. By fostering a culture of innovation, Thailand can lead in sustainable resource management and circular solutions. (Ministry of Science and Technology, National Science and Technology Development Agency, Ministry of Industry, Department of Industrial Works Office of the National Economic and Social Development Council, Thailand Board of Investment, Private Sector and Industry Associations, Universities and Research Institutions)	M	3	L

Action	Description	Urgency	Co-benefits	Feasibility
Circular Procurement	Promoting circular procurement practices is essential for driving demand for sustainable products and services in Thailand. The government can lead by incorporating circularity criteria into public procurement. Clear guidelines for evaluating product and service circularity will encourage businesses to adopt circular practices. By boosting market demand for circular products, Thailand can foster innovation, investment, and progress toward sustainability goals. (Ministry of Finance, Office of the Public Procurement, Ministry of Commerce, Department of Internal Trade, Ministry of Industry, Thailand Board of Investment, Office of the National Economic and Social Development Council, Private Sector and Industry Associations, Environmental Non-Governmental Organizations)	M	2	HL
Product Design Improvements	Thailand can encourage businesses to focus on eco-design principles, such as durability, repairability, and recyclability, in product development. Offering incentives and support for sustainable design will help reduce waste and improve resource efficiency. Designing products for easy disassembly and component reuse can extend their lifespan, minimize new resource extraction, and reduce environmental impact. (Ministry of Industry, Department of Industrial Works, National Science and Technology Development Agency, Thailand Board of Investment, Office of the National Economic and Social Development Council, Private Sector and Industry Associations, Environmental Non-Governmental Organizations, Universities and Research Institutions)	M	2	L
Enhanced Material Recycling	Thailand should develop and invest in robust recycling infrastructure and technologies to facilitate efficient collection, sorting, and processing of recyclable materials. By establishing comprehensive recycling programs and promoting consumer awareness and participation, Thailand can increase recycling rates and divert more waste from landfills. Partnering with the private sector and	M	2	M

Action	Description	Urgency	Co-benefits	Feasibility
	incentivizing investment in recycling facilities can accelerate the transition to a circular economy. (Ministry of Natural Resources and Environment, Department of Environmental Quality Promotion, Department of Local Administration, Ministry of Industry, National Science and Technology Development Agency, Thailand Board of Investment, Local Government Units and Municipal Authorities, Private Sector and Industry Associations)			

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FROM GROWTH AT ANY COST TO GROWING SUSTAINABLY

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1. FROM GROWTH AT ANY COST TO GROWING SUSTAINABLY

1.1. THAILAND'S ECONOMIC ASPIRATIONS

Thailand is working towards achieving the status of a high-income economy by 2037, guided by the principles of "security, prosperity, and sustainability" outlined in its 20-year 2017 National Strategy Preparation Act. The National Strategy outlines five key objectives: economic prosperity, social well-being, human resource development and empowerment, environmental protection, and public sector governance. However, both the pre-pandemic economic slowdown and the pandemic's impact present challenges to Thailand's ambitious goals.

The current focus of Thailand's 4.0 vision is on innovation, reducing dependence on commodities, and transitioning towards a Bio-Circular-Green (BCG) economy model. This model proposes to integrate bio-economy, circular economy, and green economy concepts to create high-value, eco-friendly products, as well as a services-oriented economy with reduced resource inputs that preserves natural and biological resources. The 20-year National Strategy emphasizes investment, sustainable industrial development, resilient infrastructure, digital transformation, green tourism, small- and medium-sized enterprises (SMEs), human capital, and support for the service sector. The government aims to implement policies supporting this new framework to attract investment, enhance the business environment, and promote sustainable development. Despite existing economic challenges, the government remains committed to stimulating growth and job creation, improving competitiveness, and enhancing the overall well-being of the population and the environment.

This report examines the link between economic growth and the natural environment in Thailand. It updates the current BCG model and places a particular focus on the challenge from climate change. The report finds that an expansion of the BCG framework (see Box 1) presents opportunities to enhance both the quality and quantity of future economic growth. It places a focus on resilience to the increasing threat of climate shocks and shows the need to develop a holistic approach to economically, socially, and environmentally sustainable development.

1.2. EMERGING CONSTRAINTS ON GROWTH

Thailand has achieved significant development progress over the past 40 years, moving from a low-income to an upper-middle-income country. The economy experienced substantial growth, averaging 7.5 percent annually from 1960 to 1996 and maintaining a 5 percent growth rate during 1999-2005, even amid the challenges of the Asian financial crisis. The economic expansion resulted in the creation of millions of new jobs, playing a vital role in reducing poverty.

Other improvements included increased access to education for children, and health insurance coverage for much of the population.

Box 1. Defining sustainable development: BCG and BCG+

Thailand's government introduced the BCG model in 2021 as a way of promoting inclusive and sustainable growth. The BCG model aims to combine Thailand's biological and cultural diversity with technological innovation to create a new growth paradigm.

The BCG strategy focuses on four sectors:

- Food and agriculture
- Human health
- Bio-based material and energy
- Tourism and the creative economy

Thailand's BCG strategic plan covers 1) promoting sustainable resource use; 2) strengthening communities; 3) using technology to boost competitiveness, and 4) building resilience.

This report updates the BCG model for current circumstances, which we call BCG+. We place more emphasis on resilience to climate shocks that impact Thailand. We also focus more on measures to reduce Thailand's emissions because technology advances have created opportunities for policies to reduce emissions while simultaneously cutting energy costs. The sustainable use of Thailand's natural resources is explored. Finally, while recognizing the importance of the four BCG sectors to Thailand's economy, this report takes a whole-economy perspective so that BCG+ is assessed within the context of broader economic development.

For more than a decade, though, Thailand has faced a persistent growth challenge marked by a prolonged and noticeable deceleration in economic growth. The pivotal moment in this trajectory was the Asian financial crisis of 1997, which inflicted substantial economic damage, created a reluctance to embrace change, and resulted in a stagnation of reform efforts. In the aftermath of the crisis, Thailand encountered a series of adverse economic shocks, particularly impacting potential growth with a significant decline in investments, that accounted for about two-thirds of the average GDP decrease that occurred between the periods of 1980-1996 and 2000-2019.

The challenge has been further accentuated by a policy emphasis on consumption, which has inadvertently strengthened a cycle of low investment and slow economic growth. Focusing on consumption has increased environmental pressures and has led to lower investment and capacity for long-term growth. The pandemic caused further disruption to Thailand's economy, with GDP falling by 6.2 percent in 2020 and recovery taking longer than in peer countries. Economic slowdown in China and high energy prices linked to the continued war in Ukraine will also continue to hinder growth. In the medium term, the expected annual growth rate is 3 percent.

1.3. CROSS-CUTTING CHALLENGES TO FUTURE GROWTH

Thailand confronts multifaceted challenges across various human capital dimensions. The educational system is yielding poor outcomes, with diminishing educational spending and increasing inefficiencies. Social exclusion is pervasive among vulnerable groups, such as the elderly, persons with disabilities, women, irregular migrants, ethnic minorities, and those residing in conflict areas. Policies aimed at supporting these populations lack precision. The demographic transition towards an aging population poses a significant challenge, straining the public health system and escalating associated costs.

Thailand is grappling with significant economic challenges stemming from a loss of competitiveness in the manufacturing sector. These challenges have led to a decline in its share of global production and a lag in advanced service sectors. Ongoing challenges in financial resource allocation persist, characterized by high household indebtedness and limited access to finance for small and medium-sized enterprises (SMEs). Furthermore, the slow adoption of technology and innovation poses a significant barrier to progress in transitioning towards a Bio-Circular-Green (BCG) economy model. Addressing these multifaceted issues is imperative for revitalizing economic growth and fostering a more sustainable and competitive economic landscape in Thailand.

1.4. SPECIFIC CLIMATE AND ENVIRONMENTAL CHALLENGES

Since the launch of the BCG economic model, several specific environmental issues have risen in prominence: (i) climate vulnerability, (ii) carbon emissions and commitments made to reduce them, and (iii) degradation of natural resources.

1.4.1. Climate vulnerability

Thailand is highly vulnerable to climate change, ranking as the world's eighth most-impacted country by extreme weather events in the last two decades. The country is especially vulnerable to the effects of climate change because of its long coastlines, fragile agriculture system, susceptibility to extreme weather events (tropical storms, floods, and droughts), and poorly planned urban expansion. Recent model projections show that, in the absence of action to prevent urban flooding, most of the Greater Bangkok area could be underwater by 2050 (Climate Central, 2019), displacing an estimated 12 million people — many of them already living below the poverty level. Climate-related disasters affect medium-term growth potential, with large and long-lasting macroeconomic effects, and come with significant social costs in terms of lost lives, food insecurity, and deterioration in human capital. Specifically, the relatively poor North and North-Eastern regions of Thailand are highly vulnerable. If unaddressed, climate change has the potential to exacerbate inequality in the country.

A combination of sea level rise and changing weather patterns could further accelerate erosion along Thailand's long coastlines. The Third Biennial Update Report (Ministry of Natural Resources and Environment, 2020) concludes that about 600 kilometers (23 percent of Thailand's coastline) is affected by an erosion rate of one to five meters per year. The total loss of land is estimated at two square kilometers per year, with a value of 6 billion Thai baht (THB), which is .04 percent of gross domestic product (GDP). Cities and economic activities in coastal areas are especially vulnerable to coastal erosion.

Bangkok is particularly vulnerable to flooding and coastal erosion. The Thai capital and most populous city lies on the delta of the Chao Phraya River, approximately 25 kilometers inland from the Gulf of Thailand. The area is less than two meters above sea level and sits on former marshy land that is subject to periodic flooding. In addition, Bangkok is sinking because of excessive underground water use and the weight of large-scale high-rise development, suggesting that permanent water incursion may become possible. Thailand's Third Biennial Update Report to the United Nations notes that Bangkok is one of the most vulnerable cities in the world to the effects of changing rainfall patterns, sea level rises, and coastal erosion.

Thailand is also vulnerable to droughts and water shortages, with particularly adverse effects on the agriculture sector. Changes in weather patterns resulting from climate change are increasing the frequency of localized droughts and water shortages, as well as flooding. Agriculture (which accounts for about 9 percent of GDP) is particularly vulnerable to water shortages, with highly water-intensive rice production especially susceptible. A lack of rainfall also contributes to the overuse of fresh water from aquifers, leading to land subsidence and sinking in the central part of the country characterized by low-lying land of high economic value. Costs to the government in providing compensation (mainly to farmers) are expected to increase. In 2019, the government reportedly provided a one-off payment of THB 25 billion (0.15 percent of GDP) to farmers to compensate directly for damage to crops from drought and flooding. Further measures to support affected farmers were also announced with a cost of THB 60 billion (0.36 percent of GDP).

Other important economic sectors, including tourism and manufacturing, are also exposed to the impacts of climate change. Tourism, which is mainly located on coastlines and accounts for an estimated 12 percent of GDP, is vulnerable to flooding and coastal erosion. The manufacturing of goods for exports is concentrated in and around Bangkok and its perimeter and is therefore also vulnerable to flooding. Water supply, although small in economic terms, provides a critical input to several other sectors (including agriculture and tourism). Careful management of water resources will be important in reducing subsidence and preventing low-lying coastal areas from sinking further, but will become more difficult if the frequency of droughts increases.

Oceans are an important resource for the prosperity of Thailand. Despite their importance, the sustainability of oceans is under threat because of overfishing, degradation of mangroves and coral reefs, and marine plastic debris that significantly impact the economy of coastal areas. Climate change has added to these pressures and may also lead to an increase in their cumulative impacts.

Wildfires are becoming a common occurrence in Northern Thailand, happening every dry season, and exacerbated by climate change. Nearly 20 percent of the forested area of Northern Thailand burned down in the first four months of 2020, causing dangerous levels of air pollution. A total of 25,518 hectares (ha) burned in all of Thailand that year, causing $380 million in damages.

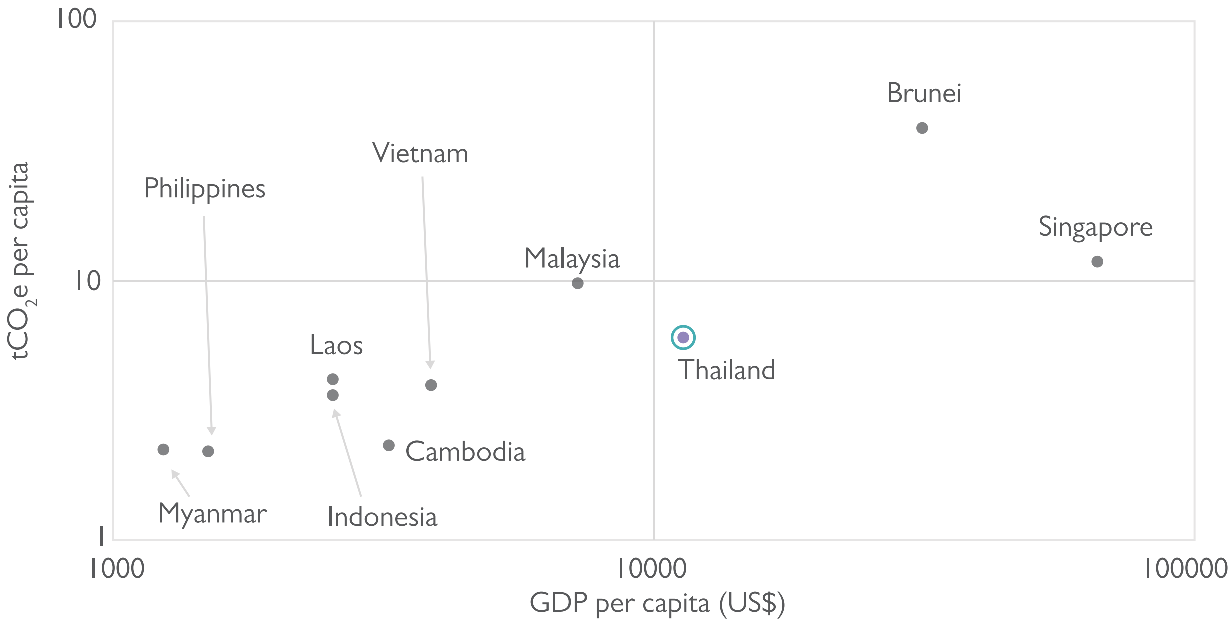
While the 2020 fires were among the worst in recent years, they were not a singular event, with some resulting from the drought and scorching heat while others were caused by crop burning — a common method to clear farmland that has also caused very high levels of air pollution in Northern Thailand. Long-term exposure to PM2.5 and PM10 particles emitted by wildfires can result in cardiovascular and respiratory diseases, as well as cancer.

In pursuing the BCG economic model, Thailand needs to address these climate change risks as a priority. Climate-related disasters affect medium-term growth potential, with large and long-lasting macroeconomic effects, and come with significant social costs in terms of lost lives, food insecurity, and deterioration in human capital. Specifically, the relatively poor north and north-eastern parts of Thailand are highly vulnerable to climate change. If unaddressed, climate change will become the main obstacle to the sustainability of the country in pursuing the BCG economic model.

1.4.2. Carbon emissions and commitments

Thailand is not a major contributor to climate change, but its emissions are expected to grow. The nation's greenhouse gas (GHG) emissions accounted for 0.88 percent of the total global emissions in 2022 and constituted the world's 20th largest emitter country. Its per capita emissions are comfortably below the global average but are higher than those in several other ASEAN countries, reflecting its higher income levels (Figure 1.1). Thailand's emissions per unit of GDP are also above the global average rate.

Figure 1.1. Per capita GDP and GHG emissions in ASEAN countries, 2018

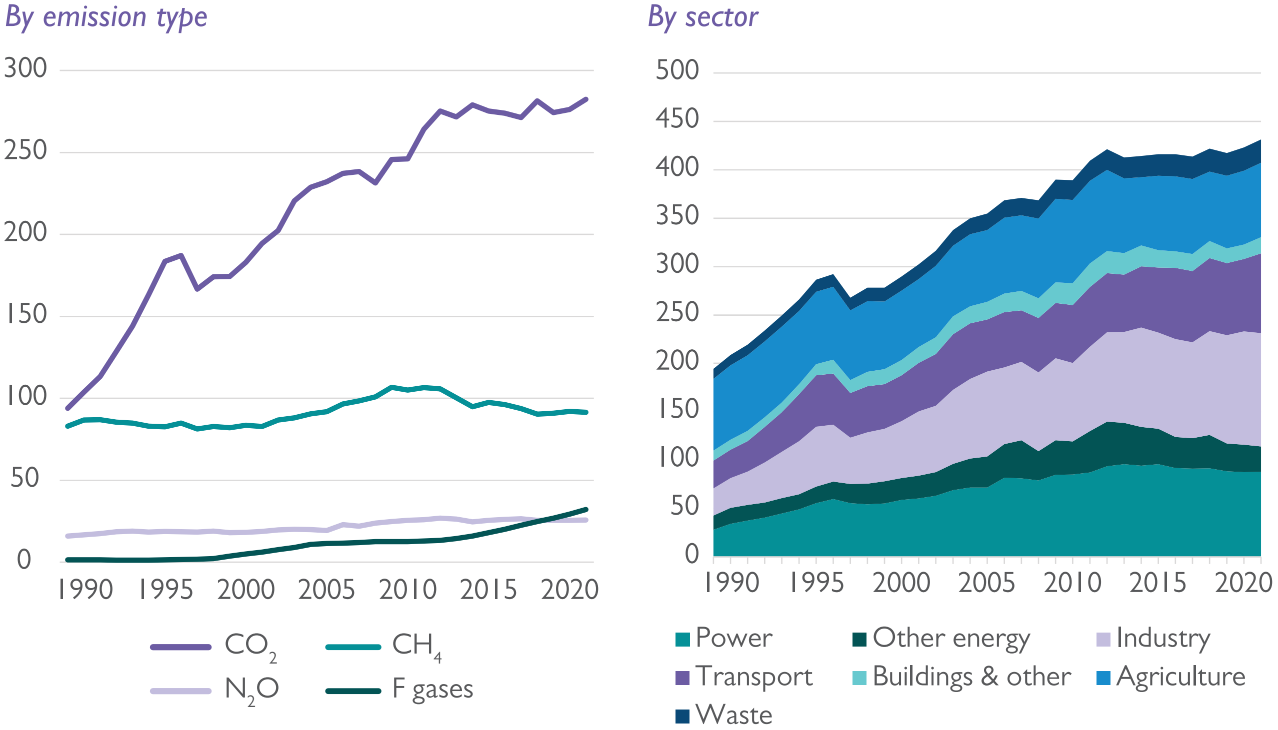


Source: CAIT and WDI Databases; *Note:* Emissions exclude LULUCF

Although from a low base, Thailand's GHG emissions have more than doubled since 1990. China and India saw much larger growth in emissions over this time (285 percent and 175 percent, respectively) but also experienced faster GDP growth. Nevertheless, Thailand's GHG intensity of GDP has moderately declined since 1990.

Industry, power, transport, and agriculture account for most of Thailand's GHG emissions. In 2018, the power sector contributed 21 percent of Thailand's total GHG emissions (Figure 1.2). Industry accounted for a 26 percent share, transport 18 percent, and agriculture 17 percent. The remaining emissions are attributed to other energy production (7 percent), waste (6 percent), and buildings (4 percent). Most power sector GHG emissions are CO_2 and most agricultural emissions are methane and nitrous dioxide. Industrial emissions include a growing proportion from F-gases. The industry, power, transport and agricultural sectors all face different decarbonization challenges in coming decades, and the availability of technological options to reduce emissions varies substantially across these sectors.

Figure 1.2. Emissions by GHG and by Sector, $mtCO_2eq$


By emission type

By sector

Source: EDGAR database (edgar.jrc.ec.europa.eu/dataset_ghg60 and data.europa.eu/doi/10.2904/JRC_DATASET_EDGAR) and World Bank staff calculations.

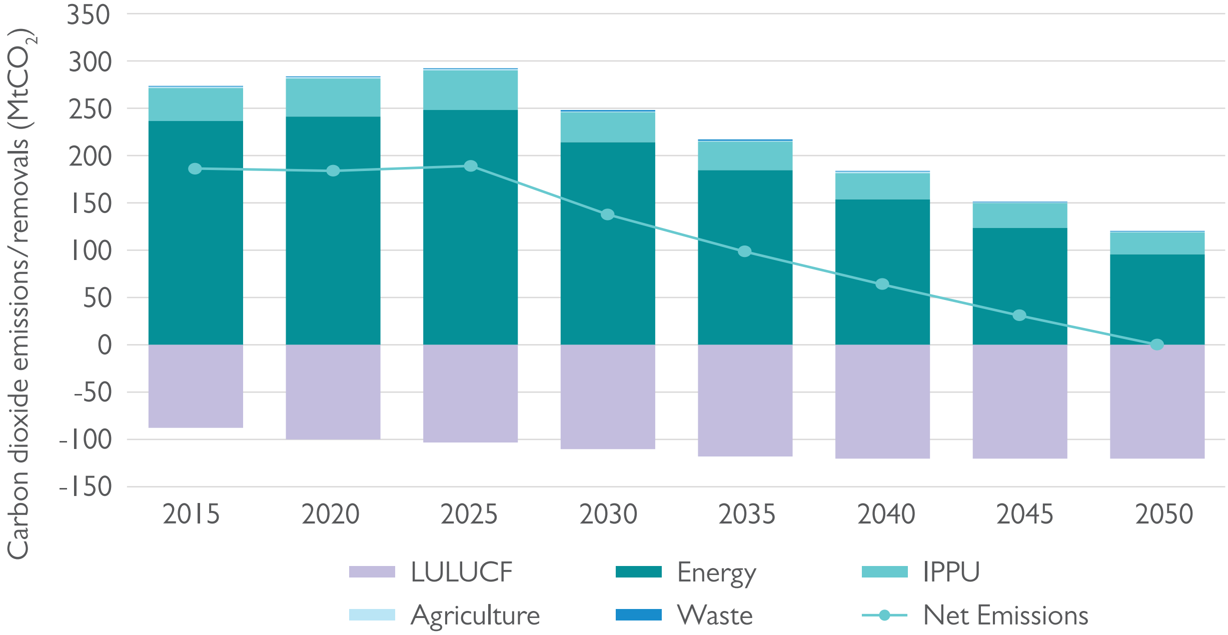
Emissions in the power sector have begun to plateau in recent years with the increasing adoption of renewable sources. Power sector emissions have long accounted for a large share of Thailand's GHGs, with fossil fuel dependence causing environmental degradation and imposing economic and health costs. More recently, a greater use of solar, wind, and liquid biofuels for electricity generation has slowed the growth of emissions from electricity and heat consumption and from the energy sector overall (Climate Watch, 2023). In 2019, 42 percent of electricity was generated from renewable sources, compared to 34 percent from fossil fuels such as coal (IEA Energy and Carbon Tracker, 2020). These green technology shifts have also contributed to generating more green jobs and reducing the cost of electricity for households and businesses in Thailand.

Since 2018, industrial processes and product use (IPPU) have been the second largest contributors to GHG emissions in Thailand, followed closely by the agriculture sector. In 2020, the IPPU sector accounted for approximately 20 percent of GHG emissions in Thailand, while the agriculture sector accounted for approximately 15 percent of overall emissions. GHG emissions from industrial processes are driven primarily by mineral production — constituting about 60 percent of IPPU emissions in 2016 — as well as the production of chemicals, metals, and non-energy products from fuels and solvents.

The challenge for Thailand is that no country has transitioned to high-income status while simultaneously reducing emissions. Although overall progress has been made in reducing emissions while growing GDP, results at the country level have been mixed. Decoupling GDP growth from GHG emissions also can be temporary, and decoupled countries may revert to increasing emissions to maintain economic expansion. Nevertheless, there are encouraging signs of relative decoupling in Thailand, where the rate of emissions growth is slower than that of economic growth. From 1990 to 2022, the growth of real GDP (212 percent) surpassed the growth of all GHG emissions (109 percent) and CO_2 emissions from energy (206 percent) during the same period, indicating (at best) relative decoupling but not absolute decoupling.

Thailand has committed to achieving carbon neutrality by 2050 and net zero emissions by 2065, while the country is also aspiring to become a high-income economy by 2037. In line with the global commitments made by countries under the Paris Agreement, Thailand submitted a new Long-Term Low Greenhouse Gas Emission Development Strategy (LT-LEDS) to the UN Framework Convention on Climate Change (UNFCCC) in 2021, pledging to peak emissions by 2030 (Figure 1.3). The LT-LEDS is consistent with Thailand's current Nationally Determined Contribution (NDC) and will guide the country towards low-carbon development as a basis for enhancing its subsequent NDCs. It builds on previous plans and lays out an approach for emission reductions, with a strong focus on the electricity and transport sectors. Achieving both targets is a challenging task; advanced technology and bio-circular-green alternative business models will be needed to boost the country's economic productivity while reducing GHG emissions and addressing other sustainability issues.

Figure 1.3. Thailand's Long-Term Low Greenhouse Gas Emission Scenario



Source: LT-LEDS, 2021

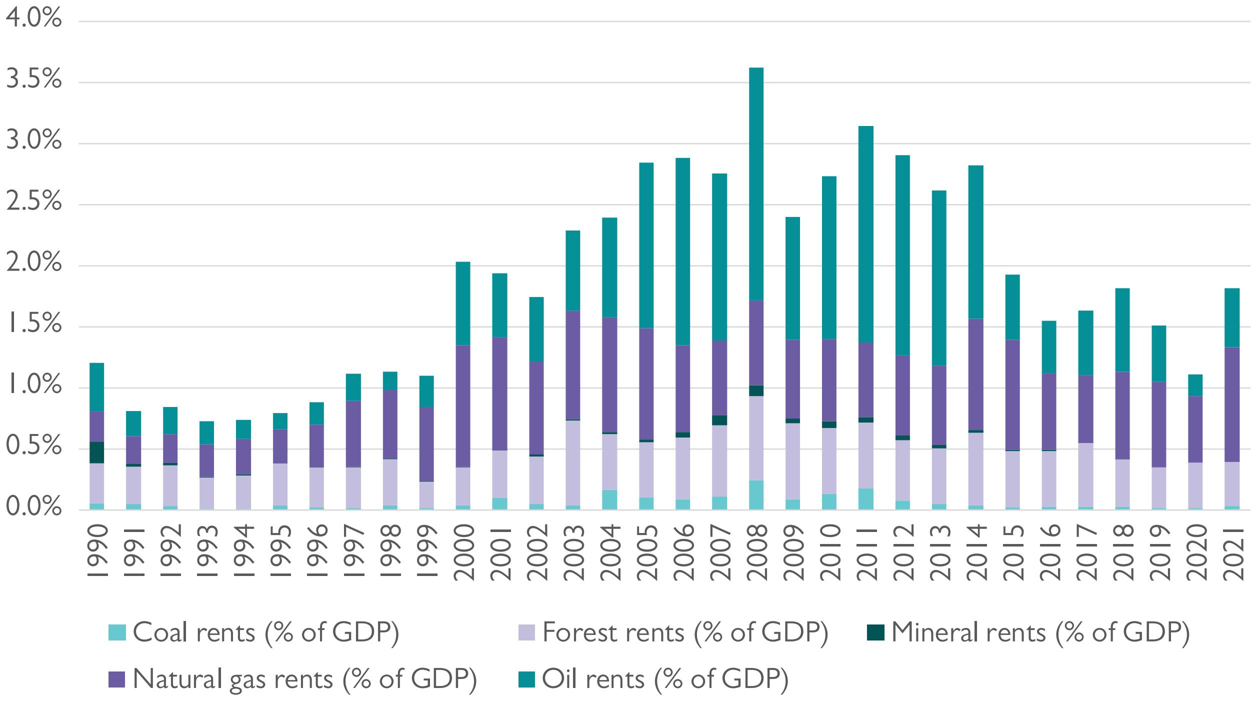
1.4.3. Degradation of natural resources

Thailand's rich natural capital has played a key role in supporting local livelihoods. Natural resources such as forests, watersheds, marine and coastal ecosystems, and mineral resources have supported Thailand's industries and driven its economic growth. Multiple forms of capital interact to generate goods and services, and adequately valuing natural capital will help to achieve more sustainable development. For example, fish productivity will depend on fish stocks (natural capital), which in turn depend on the distribution and quality of natural habitats (natural capital), fishing boats (manufactured capital and financial capital), skills of fishermen (human capital), and on fishing policies and governance (social capital) (Guerry et al., 2015).

Natural resources have been one of the key drivers of Thailand's development, especially from 2003 to 2014. In this period the value of natural resource rents as a share of GDP more than doubled compared to 1990, reaching a peak of 3.6 percent of GDP in 2008 (Figure 1.5). The majority of these natural resource's rents come from oil, natural gas, and forests.

As recognized in the BCG strategy, Thailand's biodiversity is among the richest in Southeast Asia. Thailand's ecosystems account for 8-to-10 percent of plant and animal varieties in the world. Biodiversity supports ecosystem functions that provide benefits to communities and help sustain livelihoods, as well as key sectors of the country's economy (e.g. agriculture, forestry, and tourism). Some ecosystems provide indirect or non-market values such as forested riparian buffers that prevent erosion and sediment runoffs and improve water quality, mangroves that stabilize coasts and limit damages from storm surges, and forests and marine environments that store carbon and provide recreational opportunities.

Figure 1.4. Resource rents as percent of Thailand's GDP



While Thailand's economic growth has relied heavily on natural resources, it has also degraded local environments. The enforcement and monitoring of the implementation of Environmental Impact Assessments (EIAs) remain a challenge. There is limited awareness and engagement on environmental issues, resistance to change from stakeholders who may be negatively affected by environmental regulations and policies, and inadequate government resources and systems in place.

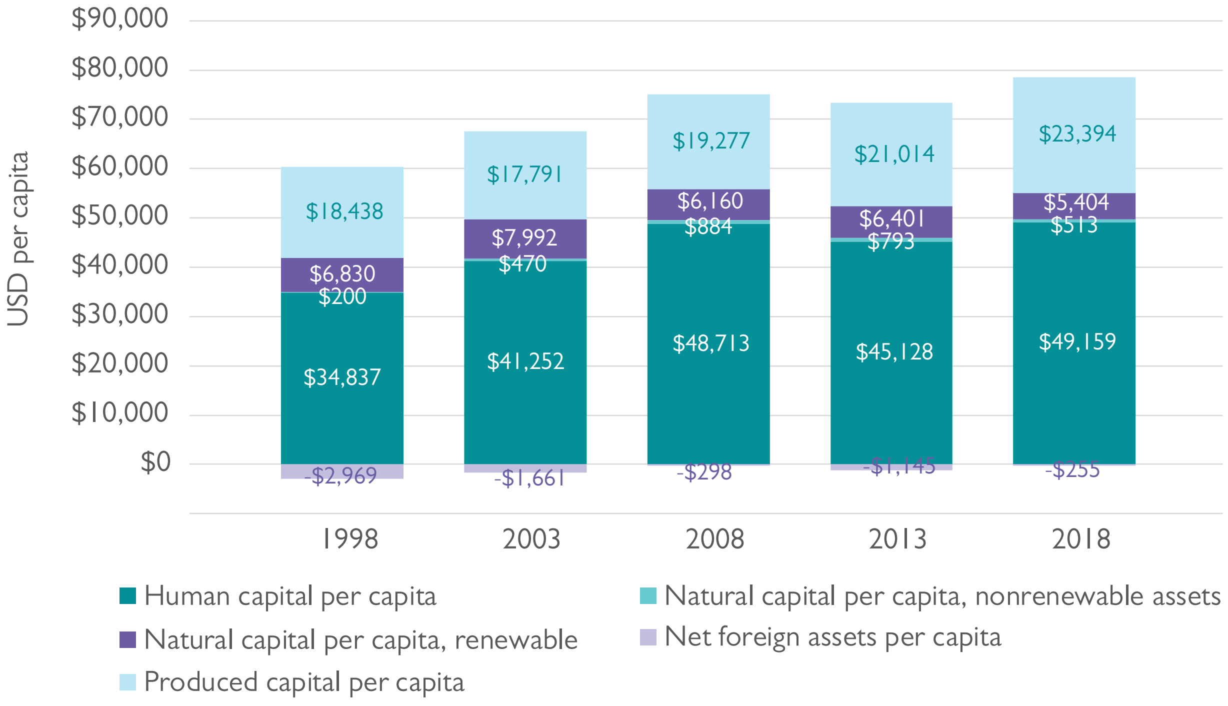
Despite substantial socio-economic benefits, biodiversity remains undervalued in Thailand and is facing multiple threats. These threats include climate change, illegal wildlife hunting and logging, forest fires, forest clearing, expansion of urban areas and land use changes, livestock overgrazing, destructive fishing practices, pollution, and invasive alien species (CBD, 2023). More than 13 percent of all species in the country are estimated to be threatened with extinction (Department of International Organizations - Ministry of Foreign Affairs of Thailand, 2021).

Water availability is falling because of excessive water consumption from rice production. As one of the world's largest rice exporters, Thailand's agricultural sector —dominated by rice cultivation — demands vast amounts of water for irrigation. Traditional rice farming methods, which rely heavily on flooding fields, exacerbate this problem. This practice not only depletes local water resources but also leaves them susceptible to climate variability, such as prolonged dry seasons and unpredictable rainfall patterns. Consequently, the competition for water between agricultural needs and other sectors — including urban and industrial use — increases to make sustainable management of water resources imperative to support both food security and economic stability in Thailand.

Despite efforts to increase forest coverage, the overall share of forested land in Thailand is decreasing. In 2020, forests covered 31.6 percent of Thailand's land mass, down from a corresponding share of 33.4 percent in 2008. Despite efforts by several agencies in Thailand to promote reforestation, satellite images show that the level of forest coverage is decreasing by around 0.3 percent per year. Some forest has been degraded because of natural forest fires. However, the main reasons for deforestation are human encroachment and illegal logging. At sea, mangrove forests have been cleared for shrimp farming, with the pollution from these farms causing further damage.

The value of renewable natural capital per capita decreased by 21 percent between 1998 and 2018 (Figure 1.5). There were declines specifically in the values of fisheries, mangroves, and protected areas (Figure 1.6). During the same period, the value of produced capital increased (by nearly 27 percent), as did non-renewable assets (nearly 157 percent) and human capital (over 41 percent).

Figure 1.5. Components of Thailand's national wealth per capita



Adjusted Net Savings (ANS), which serves as a crucial gauge for sustainable development, has declined notably since 2020. ANS measures national savings defined as national income minus total consumption, plus net transfers – adjusted for gains on education spending and losses on consumption of fixed capital, depletion of minerals and forests, and air pollution. A negative ANS could indicate unsustainable development, i.e. diminishing assets to fuel present growth. Although ANS has increased since 1990, it showed a sharp decline from 2019 ($1,114 per capita) to 2020 ($797 per capita) (Figure 1.7). Economic losses, particularly due to natural resource depletion and carbon dioxide and particulate emission damage, rose steeply from $38 to $230 per capita per year from1990 to 2020. Overall, ANS was at its lowest in 2001 at $183 per capita.

Figure 1.6. Components of natural resource wealth per capita over time

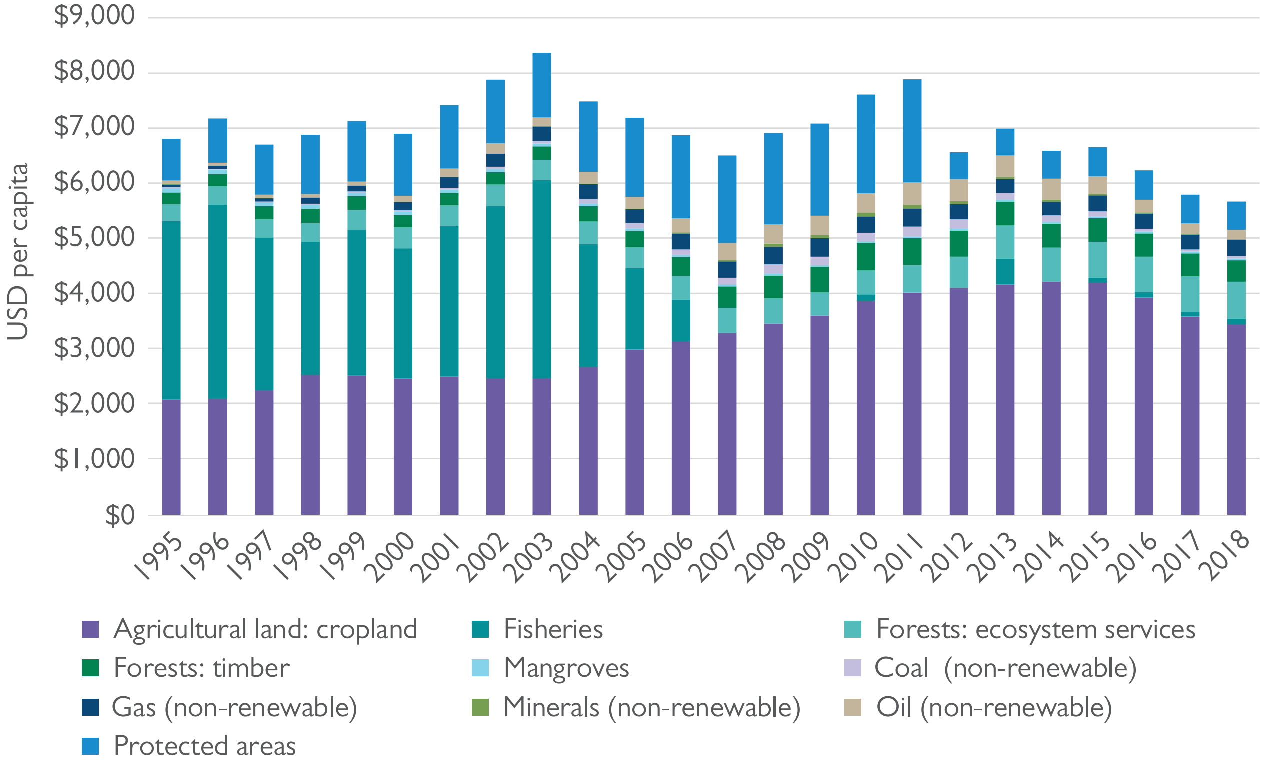
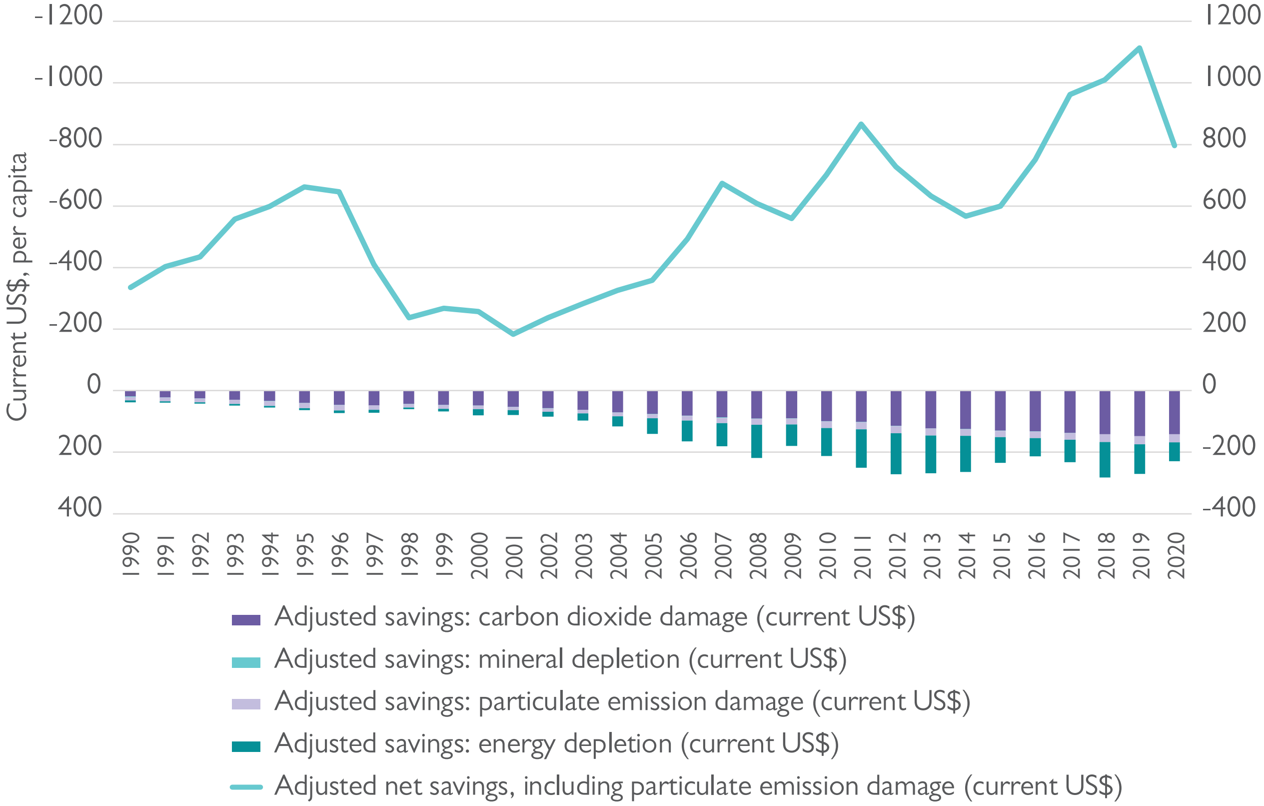
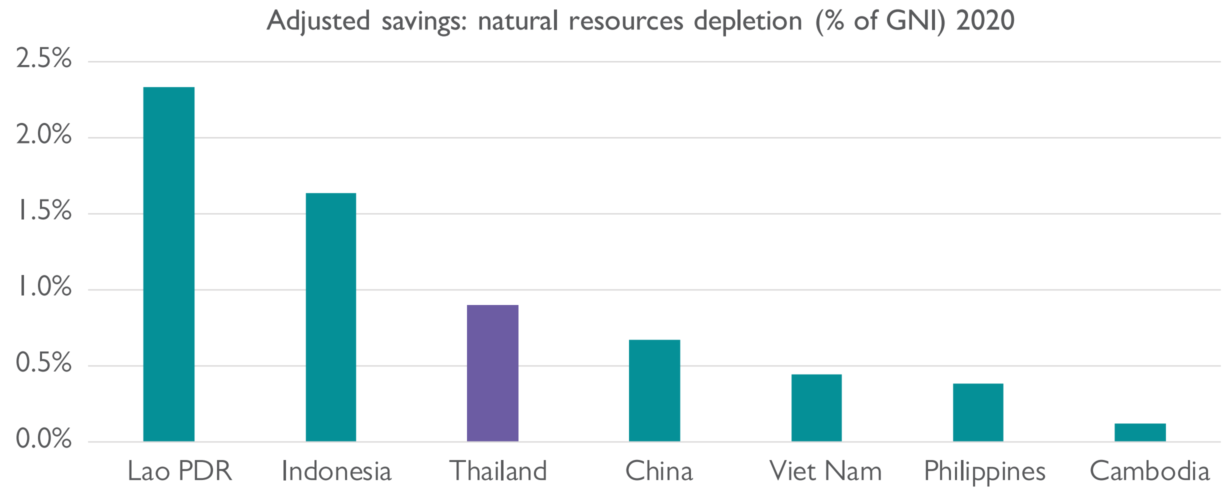


Figure 1.7. Net natural resource wealth depletion in Thailand



Thailand has similar rates of natural wealth depletion to China. It is leveraging a greater share of its natural resources to promote GDP growth than Vietnam, Philippines, and Cambodia, but less than Lao PDR and Indonesia (Figure 1.8).

Figure 1.8. Adjusted savings – natural resources depletion in Thailand as percent of GNI compared to neighboring countries



Poor air quality is estimated to have caused 32,211 premature deaths a year and cost the economy $33 billion (6 percent of GDP) in 2019. Air pollution, particularly from PM2.5 and PM10, continues to be a major challenge, costing the economy in terms of health expenses and human resource productivity. Air pollution is normally found in industrial zones, cities, and areas with high levels of agricultural burning and forest fires. Despite plans and acts to address air quality, enforcement remains a challenge.

A shift to a more circular economy could reduce pressure on natural resources in Thailand. The circular economy model aims to limit the extraction of non-renewable resources and limit generation of waste. Aspects of the circular economy include extending product lifetimes, sharing durable goods, and the repair, reuse, and recycling of materials. It contrasts to the current linear mode of production in which materials are extracted, used in final products, and converted to waste.

1.5. THE OPPORTUNITY FOR A NEW GROWTH MODEL THAT IS LOW-CARBON AND CLIMATE-RESILIENT

Despite the challenges from economic growth constraints, an opportunity still exists for a new growth model that combines biodiversity, low carbon policies, and climate resilience. This opportunity can be developed from the BCG economic model. The current model aims to apply the concepts of bio-economy, circular economy, and green economy to develop high-value products and services that are eco-friendly and require less resource input, while conserving natural and biological resources. This report uses modeling approaches to focus specifically on resilience to extreme weather events that will become more common because of climate change, and ways to reduce domestic airborne emissions. The report shows that adopting this 'BCG+' model could help alleviate some of the constraints to growth described in Section 1.2.

The new BCG+ growth model will require the introduction of policies to decouple economic growth from environmental and natural resource impacts, while managing biodiversity and climate change challenges. Advances in technology may encourage the adoption of some sustainable practices, but policy will be needed to drive the direction of change. For example, incentives may be needed to generate shifts that will affect the use and management of Thailand's natural assets and induce a reallocation of all factors of production, transforming the structure of demand (consumption) and supply (production), including the adoption of bio-circular-green technology options. In pursuing green growth, Thailand needs to adopt aggressive strategies in the near term in the main emitting sectors (energy, industry, and agriculture) and enhance its sinks (forestry), combined with carbon pricing to create incentives for behavioral changes in businesses and households. The country also needs measures to reduce local air pollution, improve labor productivity, and bolster Thailand's competitiveness in a decarbonizing world. Because Thailand's economy is highly dependent on trade and foreign direct investment (FDI), the low-carbon transition in other countries will have important implications for its future development path. Thailand will also need to prioritize low-carbon development to lower emissions, and to ensure future trade and industrial competitiveness.

In this report, the focus is on the transition toward a BCG+ model and its implications. Chapter 2 assesses the risks that Thailand faces due to climate change by analyzing the vulnerabilities of key sectors like agriculture, tourism, and infrastructure to climate-related events such as extreme weather events, sea-level rise, and changing precipitation patterns from a spatial perspective. Chapter 3 elaborates on the prospects of green growth within the BCG framework, highlighting opportunities for sustainable development and economic progress. It discusses strategies such as renewable energy adoption, sustainable resource management, and eco-friendly practices across various sectors. Chapter 4 examines the concept of natural tipping points — the critical thresholds in ecosystems beyond which rapid and often irreversible changes occur — and explores how these tipping points could be reached or mitigated within the context of transitioning to a BCG economy. Recommendations are summarized in Chapter 5.

2

DEALING WITH CLIMATE RISKS

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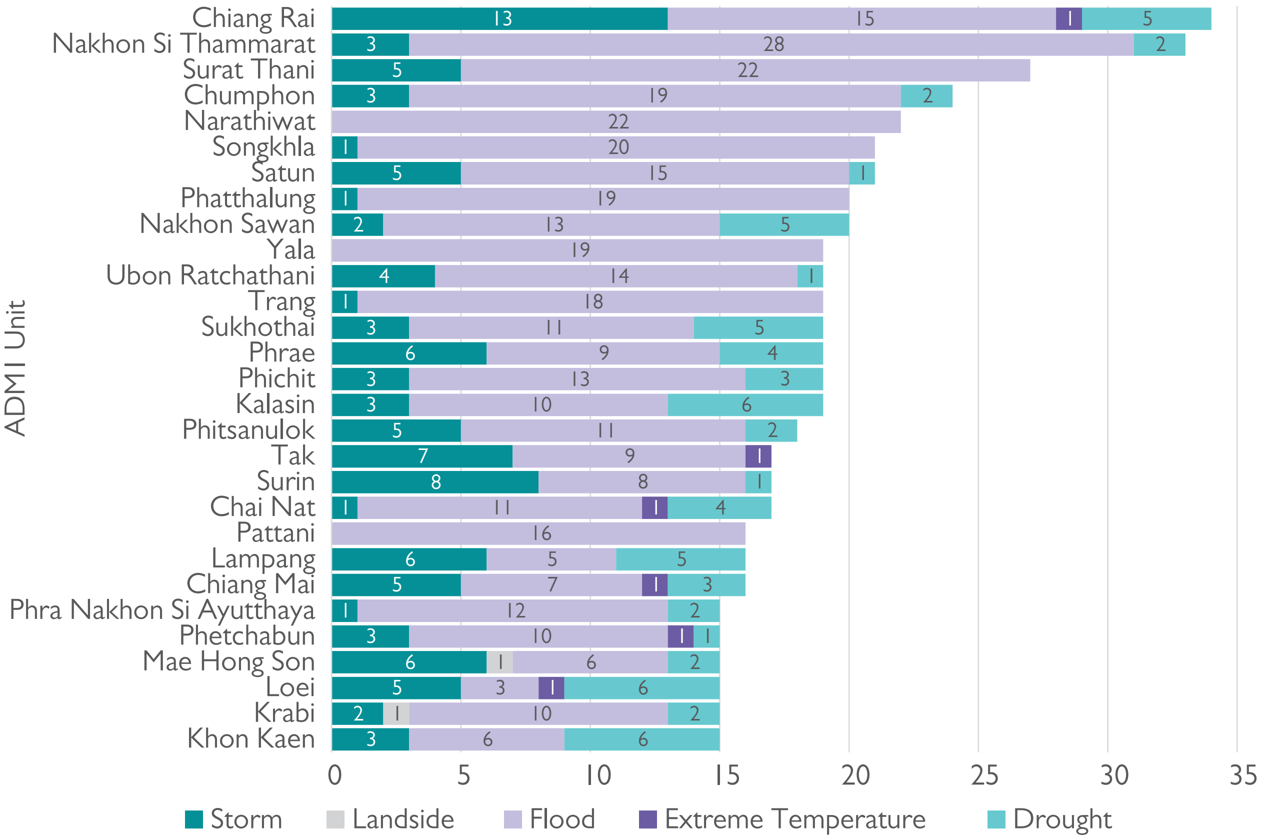
2. DEALING WITH CLIMATE RISKS

2.1. NATURAL CLIMATE HAZARDS

Thailand is vulnerable to a range of natural hazards, including floods, landslides, tropical cyclones, droughts, and coastal erosion. From 1960 to 2023, Thailand recorded a total of 159 natural disasters (EM-DAT). Figure 2.1 illustrates the distribution of these disasters by province (ADM level 1) in the 30 most affected regions. Exceptionally heavy monsoon rains have frequently led to widespread flooding, particularly in low-lying areas and river plains with inadequate drainage systems and deforestation. Over the course of 63 years, there were 96 recorded flood events. Several urban areas, including Bangkok, are highly susceptible to pluvial flooding, which impacts transportation, infrastructure, and the livelihoods of residents. In the northern and western mountainous regions, steep slopes make landslides a common occurrence during the wet season.

The southern coastal regions are at risk of tropical storms and cyclones, which bring heavy rainfall, strong winds, and storm surges. More than 45 such events have been recorded between 1960 and 2023. The peak period for tropical storms typically falls between May and November.

Figure 2.1. Disaster events reported by EM-DAT between 1990 and 2018 for Thailand



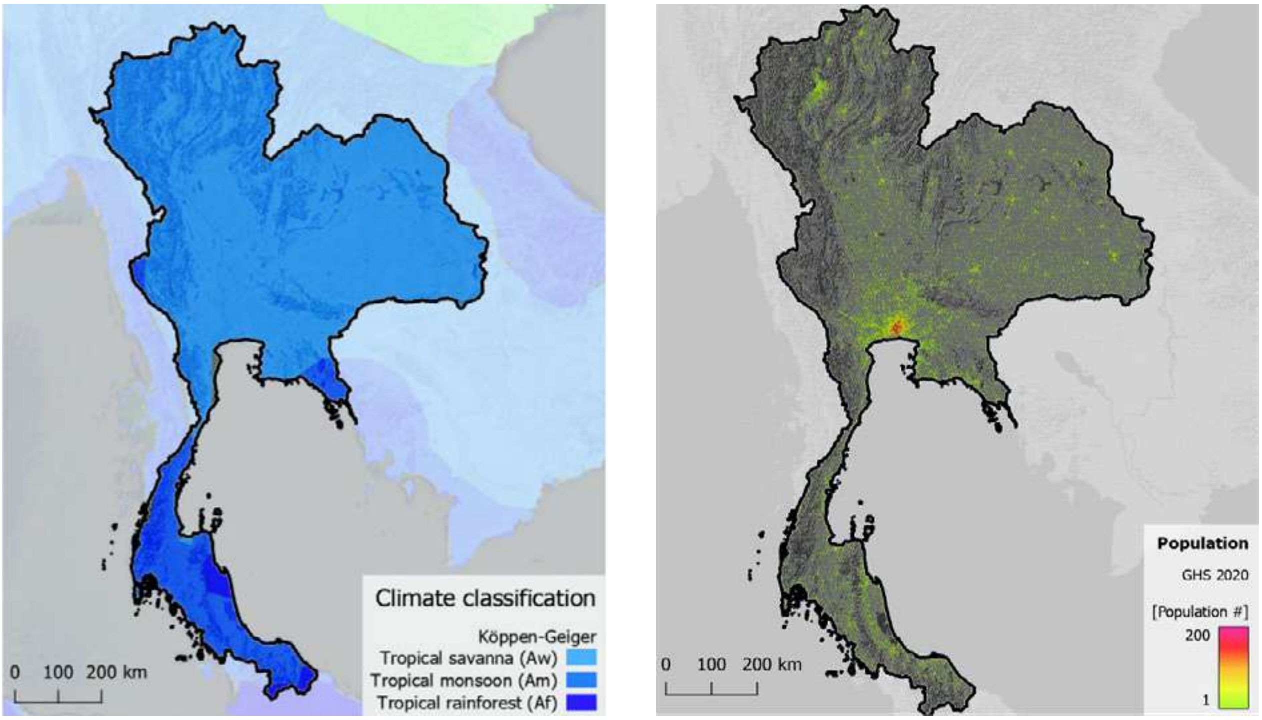
Source: EM-DAT

Droughts are also a periodic challenge in Thailand, primarily affecting the northeastern and central regions, with 12 drought-related events recorded in the last five years. In certain provinces, extreme heat stress can be a concern during the hot season, although this has only been recorded in two instances according to EM-DAT.

2.2. PHYSIOGRAPHIC REGIONS AND MAJOR CLIMATE INFLUENCES

Thailand's climate is primarily shaped by its location in the tropical monsoon zone of mainland Southeast Asia and specific topographic features that impact rainfall distribution. The climate-related risks are therefore not uniform across the country and depend on several factors, including the likelihood and intensity of a hazard, the exposure of people and their assets to these hazards, and their vulnerability to various risks. The wet season, spanning from May to October, is predominantly influenced by the southwest monsoon. During this period, the central, northern, and north-eastern regions receive substantial rainfall, with the highest precipitation levels occurring in September. Thailand is situated within the tropical zone and experiences two major climatic domains (as shown in Figure 2.2). The northern part of the country, including cities like Chiang Mai and Chiang Rai, features cooler temperatures, especially in the mountainous areas. In contrast, the southern region maintains a more consistent temperature throughout the year, with warm and humid conditions due to its proximity to the equator.

Figure 2.2. Thailand Köppen-Geiger climate classification mapped against population density



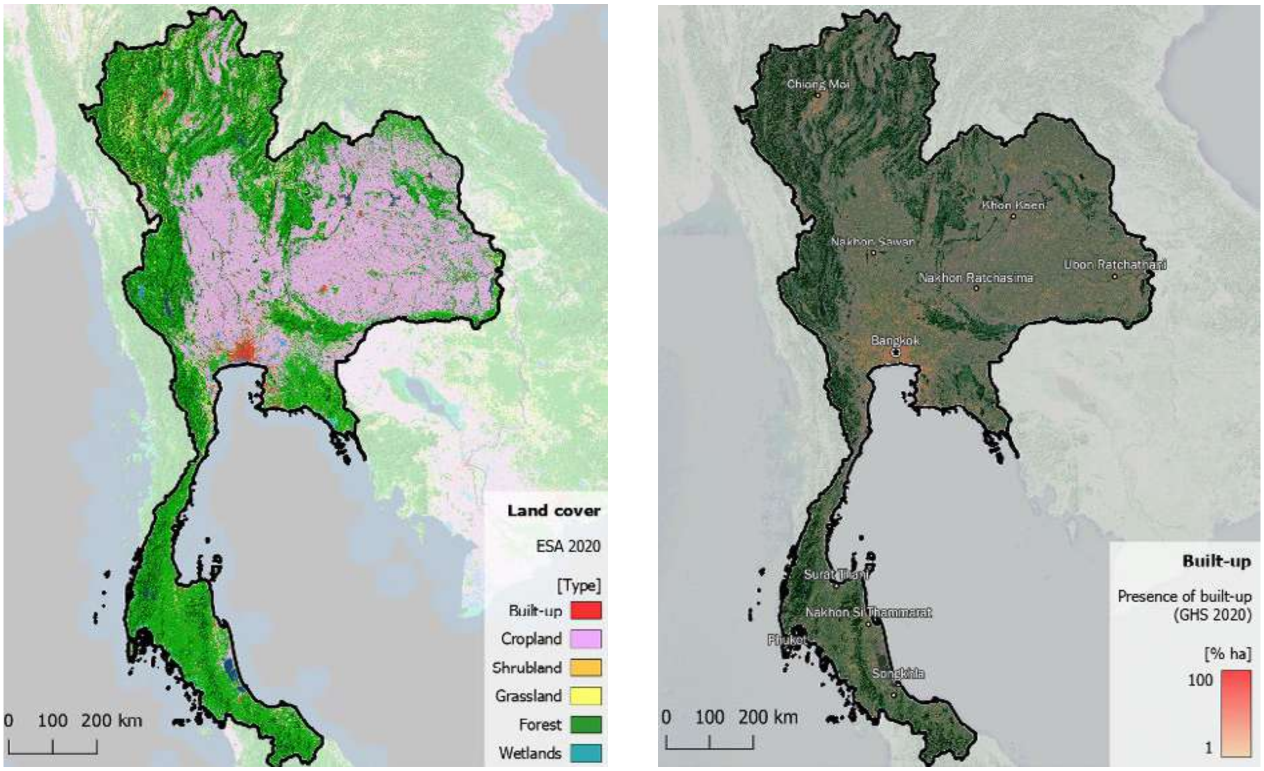
Source: Fathom Global Models and UN 2020 estimates

The importance of Bangkok makes Thailand's economy highly exposed to floods and other climate events. Since the 1960s, there has been a notable migration of people to urban centers, including Bangkok and other cities like Chiang Mai in the north, Nakhon Ratchasima (Khorat), Khon Kaen, and Ubon Ratchathani in the northeast, Pattaya in the southeast, and Hat Yai in the far south. Currently, 51.1 percent of the population resides in urban areas. The high density of population and industry around Bangkok is a key vulnerability for Thailand. Low-income households in Bangkok may be particularly vulnerable to floods. Generally, households with lower incomes are less resilient to climate-related impacts because they often reside in areas that are poor and prone to hazards. They also have limited access to critical services such as healthcare, education, and early warning systems. Additionally, these areas tend to be more densely populated.

2.3. FORESTS AND BUILT-UP AREA

Forested areas encompass a significant portion of the country, particularly in the rugged western and northern regions. The central and eastern plains consist mainly of agricultural land, with rice paddies dominating the landscape. Thailand's land cover is continually changing due to various factors, including deforestation, urban expansion, evolving agricultural practices, and shifts in land-use policies. Data from the 2020 Global Human Settlement layer (GHS) indicates that built-up assets are primarily concentrated in major cities in Thailand, especially in Bangkok and its surrounding urban areas. This distribution strongly correlates with population density (Figure 2.3).

Figure 2.3. Land cover and built-up assets



Source: ESA 2021 and GHS-BUILT-S 2020

2.4. ESTIMATING CURRENT AND FUTURE IMPACTS OF CLIMATE HAZARDS

There are two distinct methods of estimating the impacts of climate change on national economies. These methods are usually referred to as "top-down" and "bottom-up" approaches. Top-down methods use econometric techniques to explore the relationship between GDP and temperature change; a summary of estimates is provided in Kahn et al (2019). Bottom-up methods assess different types of climate impacts individually and rely more on physical data to estimate impacts. We use the bottom-up approach in this report because it gives more sectoral granularity and provides more insight for potential policy responses. This is the same approach that has been used in most of the World Bank's Country Climate and Development Reports (CCDRs). The impact channels used in this report are listed in Table 2.1. For most impact channels, average estimates of climate impacts are derived on an annual basis for RCP2.6, RCP4.5, RCP6.0, and RCP8.5. As the land cover changes, the exposure to potential hazards increases. And, the built-up assets — particularly urban infrastructure — are susceptible to the vagaries of the climate hazards.

There is considerable uncertainty about the scale of future climate impacts on Thailand's economy. Various methodological constraints exist in the published studies, including issues in identifying impacts and the question of whether climate impacts affect production levels or rates of economic growth. Distributional impacts and how these might feedback to macro-level outcomes have rarely been explored. Many of the climate impacts, in particular relating to extreme weather events, are highly uncertain themselves. Therefore, the modeling of climate impacts presented in the following sections follows a dual approach. First, estimates of GDP impacts are provided based on the figures below. Second, the models are used to assess what might happen in a year when large climate shocks occur. Such "risk-based" thinking is now becoming more common for planning purposes (Dembo, 2021), including within the financial sector.

Table 2.1. Channels of climate-related damages

Loss of labor productivity: Agriculture forestry and fish Construction
River Flood Damage
Tropical Cyclones
Losses in Agriculture: Rice Losses in Agriculture: Other Crops
Losses from fisheries
Additional costs of cooling
Losses in tourism
Losses from sea level rise including coastal erosion

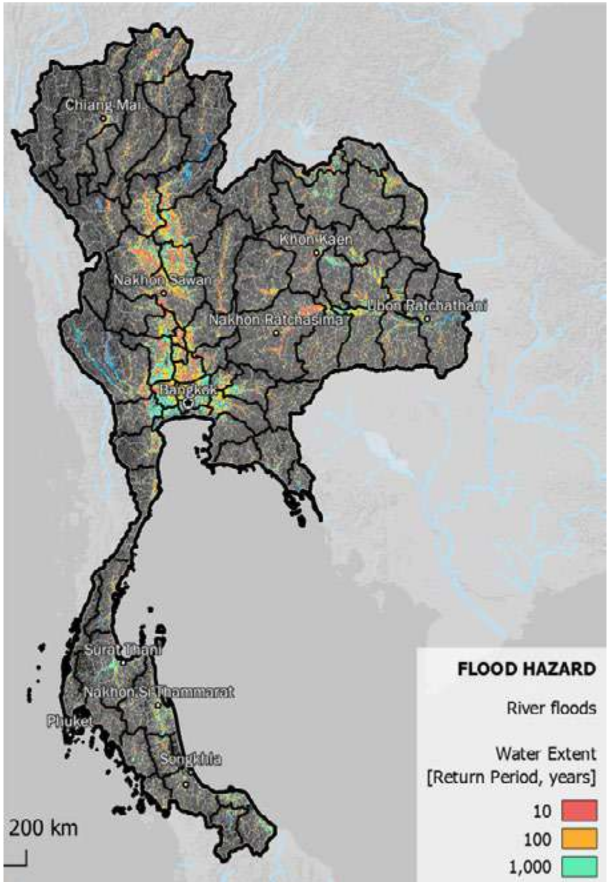
Source: Staff analysis

2.4.1. Floods and sea level rise

Floods are the most frequent natural hazard in Thailand, especially during the latter part of the monsoon season (July to October). Nearly every year, the country records significant river and pluvial floods. On average, these floods affect between 100,000 and 800,000 people annually (EM-DAT 2023).

Thailand has faced catastrophic floods in the past. One of the most recent events occurred in October 2010 when exceptional monsoon rains over the northeastern and central regions led to the Chao Phraya River overflowing. This flood affected nearly 7 million people and more than 25,000 villages in 38 provinces, resulting in more than 230 fatalities. In March 2011, an unusual amount of rainfall during the late dry season caused widespread flooding in 50 provinces, leading to approximately 160,000 ha of land being submerged and at least 53 fatalities.

Figure 2.4. River flood hazard across Thailand



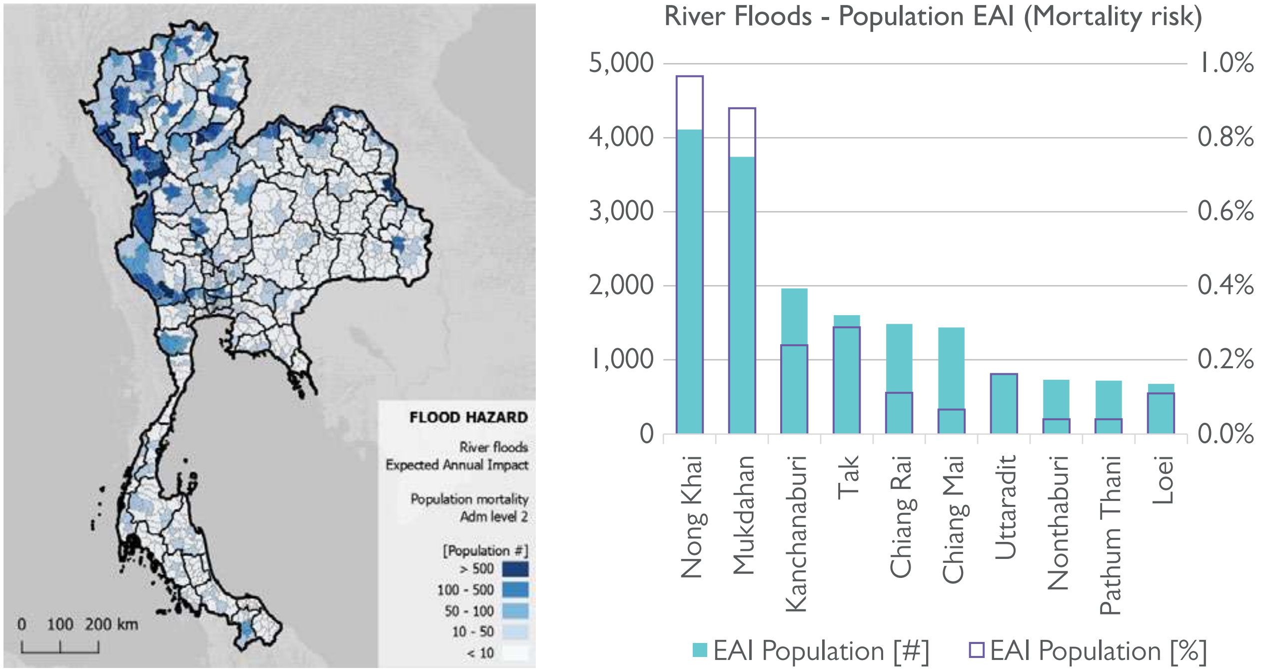
Source: Staff analysis

In July 2011, heavy monsoon rains triggered by tropical storms caused significant floods in the northern, northeastern, and central regions along the Mekong, Mun, Chi, and Chao Phraya basins. The floodwaters eventually reached Bangkok in October, and in some regions, flooding persisted until mid-January 2012. The total impact was severe, with 13.6 million people affected in 65 provinces and 815 deaths, making it one of the most severe flood events in the country's history. In October 2013, severe monsoon flooding affected 28 provinces, particularly the eastern provinces of Sa Kaeo, Prachin Buri, and Chon Buri. It led to 39 fatalities and affected more than 3 million people. In December 2014, the southern provinces of Narathiwat and Songkhla were hit by monsoon floods, causing 15 deaths. In January 2017, persistent monsoon rains resulted in flooding in the southern regions, impacting 1.8 million people and causing 95 deaths.

River floods with water depths of up to five meters or more are most prominent in the central floodplains along the Chao Phraya basin. This area includes many urban and agricultural areas. Significant flood extents are also observed in the eastern Mun and Chi catchments. Figure 2.4 illustrates the geographic distribution of hazard intensity for river flooding events with a 100-year return period.

The highest absolute and relative risk of human mortality resulting from river flood events, accounting for over 4,000 people annually on average, is concentrated along the Mekong River. This risk is particularly pronounced in areas such as Nong Khai, situated on the northeastern border with Lao PDR, and Mukdahan, located on the eastern border. Western states like Kanchanaburi and Tak expose more than 1,500 people to mortality risk. This calculation does not include water accumulation in urban areas, which is a significant factor contributing to pluvial flood hazards. Figure 2.5 below illustrates the population mortality risk associated with these factors.

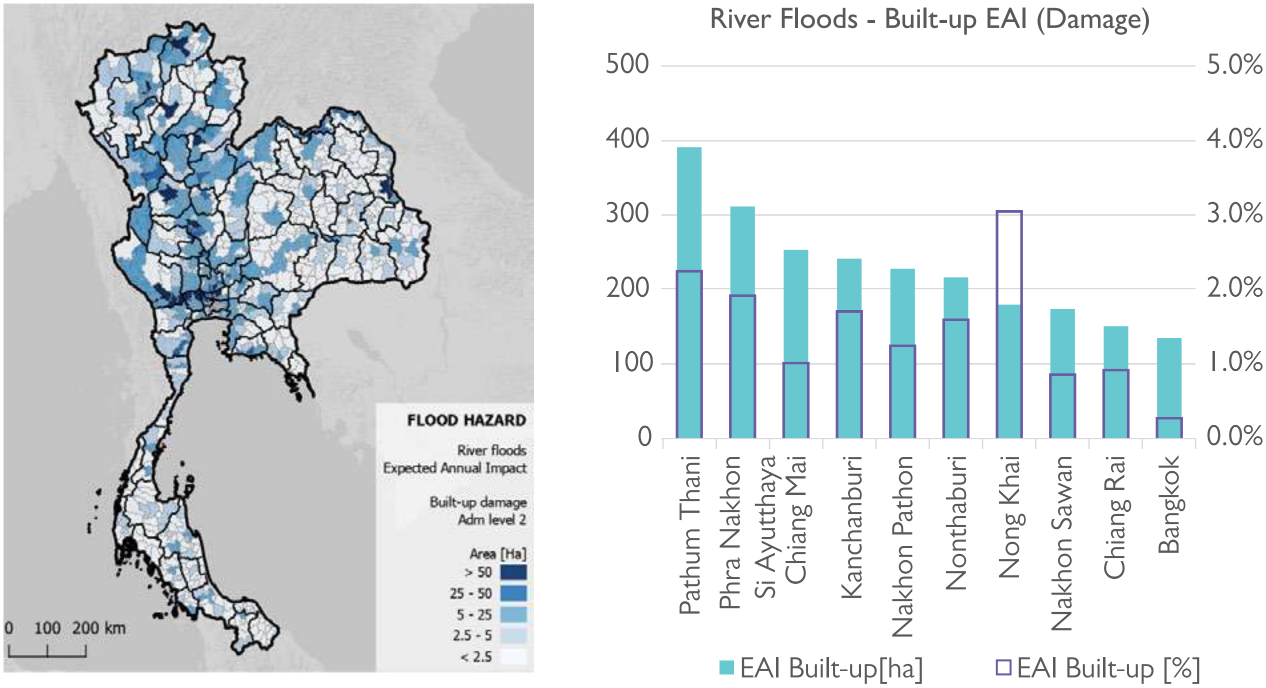
Figure 2.5. EAI of riverine floods on population mortality



Source: World Bank CCDR Studies, August 2023.

The risk to built-up areas is distributed in a somewhat different pattern. The largest risk is concentrated in the central districts located in the Chao Phraya catchment, particularly in regions such as Pathum Thani's southeastern districts, Phra Nakhon, Chiang Mai, and Kanchanaburi. Additionally, areas along the Mekong River are also significantly at risk (Figure 2.6).

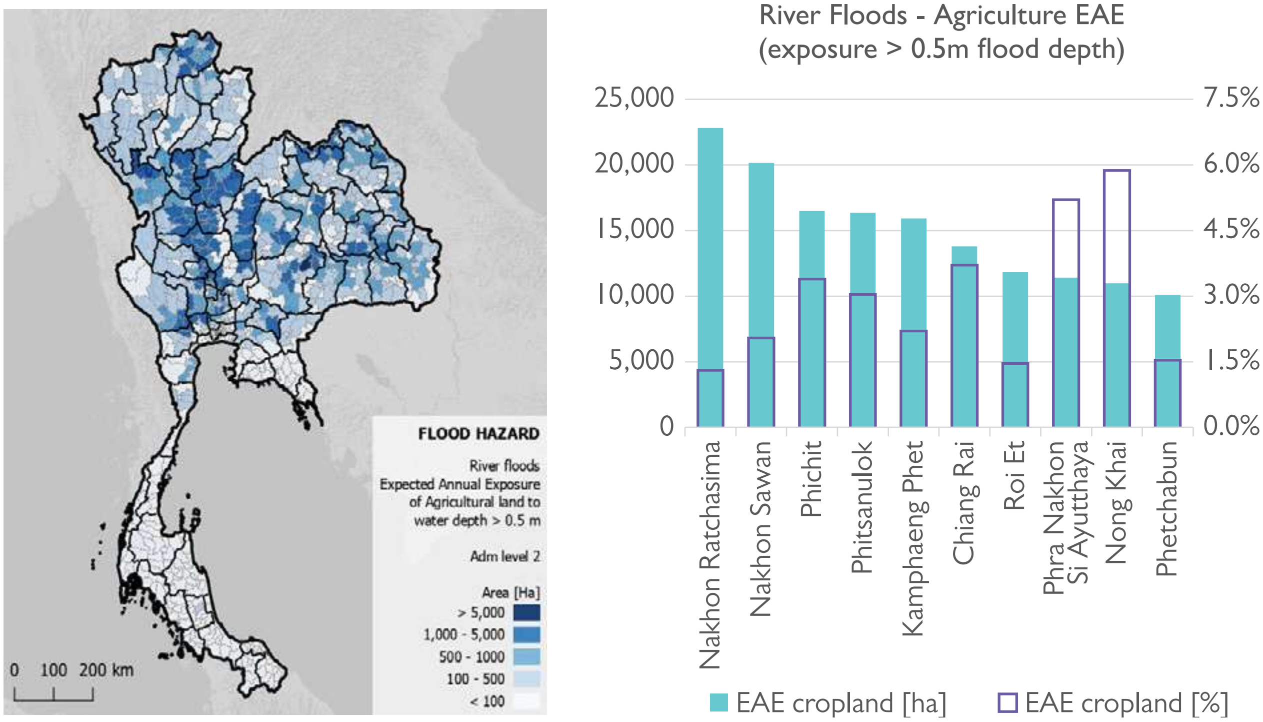
Figure 2.6. EAI of riverine floods on built-up damage



Source: World Bank CCDR Studies, August 2023.

The exposure of agricultural crops to flooding is primarily concentrated in the central plains, particularly along the Chao Phraya basin. Nakhon Ratchasima stands out with the largest relative exposure, covering more than 200 square kilometers of cropland. However, the relative distribution of exposure presents a different picture, with the highest relative exposure found in Sing Buri, where 8.6 percent of its 70 square kilometers of cropland is exposed (Figure 2.7). Some of the most vital crops in Thailand, such as rice and sugarcane, can endure prolonged submersion during the vegetative phase. The figure below provides insights into the impacts on agriculture.

Figure 2.7. EAI of agricultural land to riverine floods



Source: Staff estimates

The scale of flood damages will increase but the magnitudes are uncertain and depend on when floods occur. A warming climate leads to unpredictable rainfall patterns and increased risks of flooding. The risk of floods like the one in 2011, which was estimated to be a one-in-50-year event, could increase substantially. It is estimated that a one-in-50-year flood in 2030 could have double the impact of the 2011 floods.[1] The estimated values presented in Table 2.2 are based on a different modeling approach and are much smaller in magnitude. They are compared to a 2015 base year with damages of $127 million. The figures in Table 2.2 are used in the macroeconomic modeling in the following chapters. The estimated impacts are small, especially in the context of GDP that is growing over the projection period. However, the range of potential impacts illustrates the degree of uncertainty over future flood impacts; this is further explored in the modeling below.

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[1] WRI Aqueduct model.

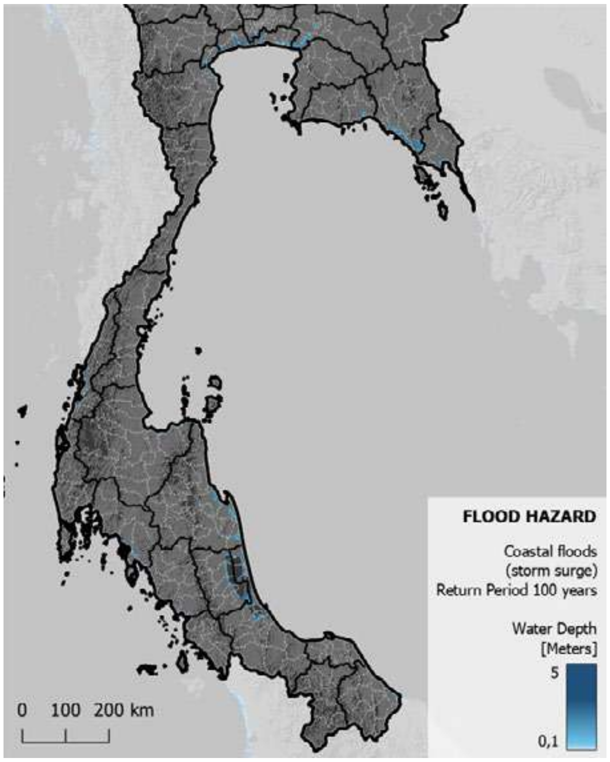
Table 2.2. Increase in expected river flood damage in 2050 from 2015 base year (USD m, 2010 prices)

	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Percent increase	11.1	17.1	14.9	36.6

Source: Climate Analytics

Coastal floods, often accompanied by coastal erosion, occur when seawater inundated low-lying coastal areas, leading to temporary or prolonged flooding. These events can be triggered by factors including tropical storms, monsoons, and high tides. Thailand has taken various measures to address this challenge, including the construction of flood defense measures such as seawalls, dikes, and flood barriers, along with regulations like coastal zoning and land-use control. Despite these efforts, coastal flooding remains a significant concern in certain districts.

Figure 2.8. Coastal Flood Hazard across Thailand (100-year return)

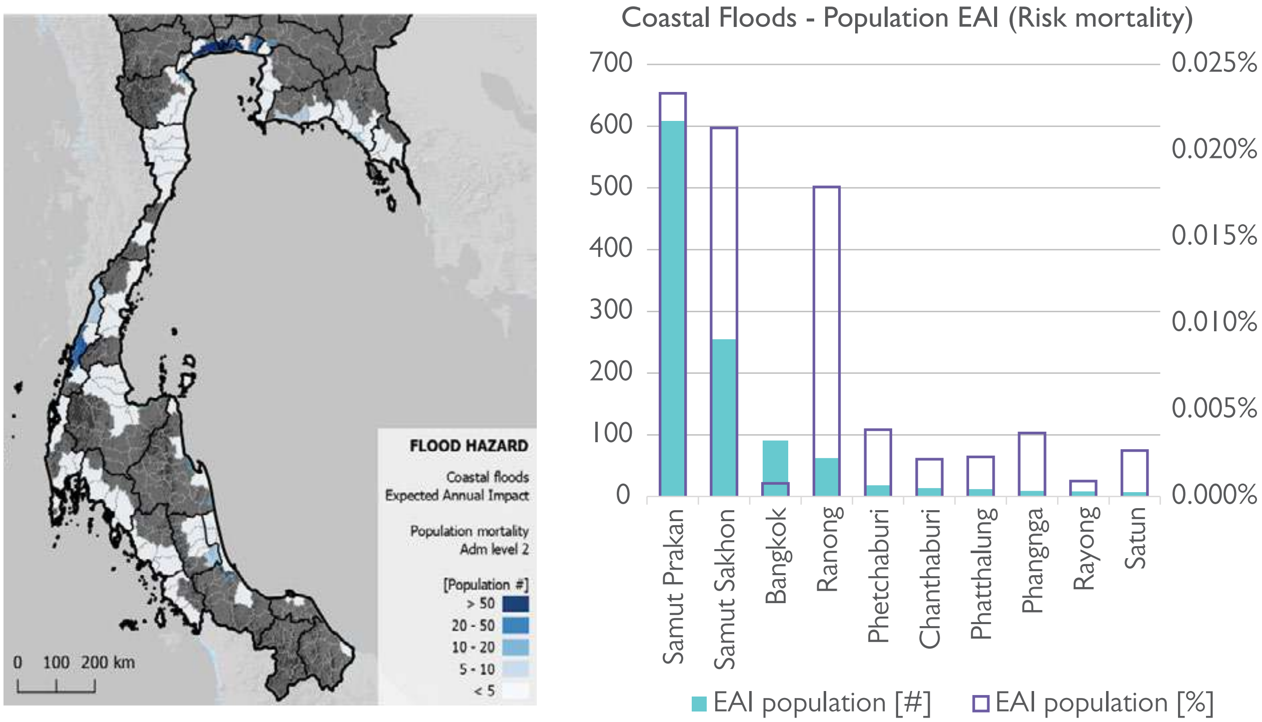


Source: Fathom Global Models, FATHOMv2

According to the OECD (2007), Bangkok ranks as the seventh-most exposed city to coastal flooding globally in terms of its population (900,000), and tenth in terms of exposed assets ($39 billion). Figure 2.8 illustrates the coastal areas prone to flooding. The most severe impacts occur within the Gulf of Thailand, particularly around the Bangkok metropolitan area, the city of Rayong, and in the southern districts of Songkhla and Phatthalung. The subsequent two figures indicate the expected impact on population mortality and infrastructure (Figures 2.9 and 2.10).

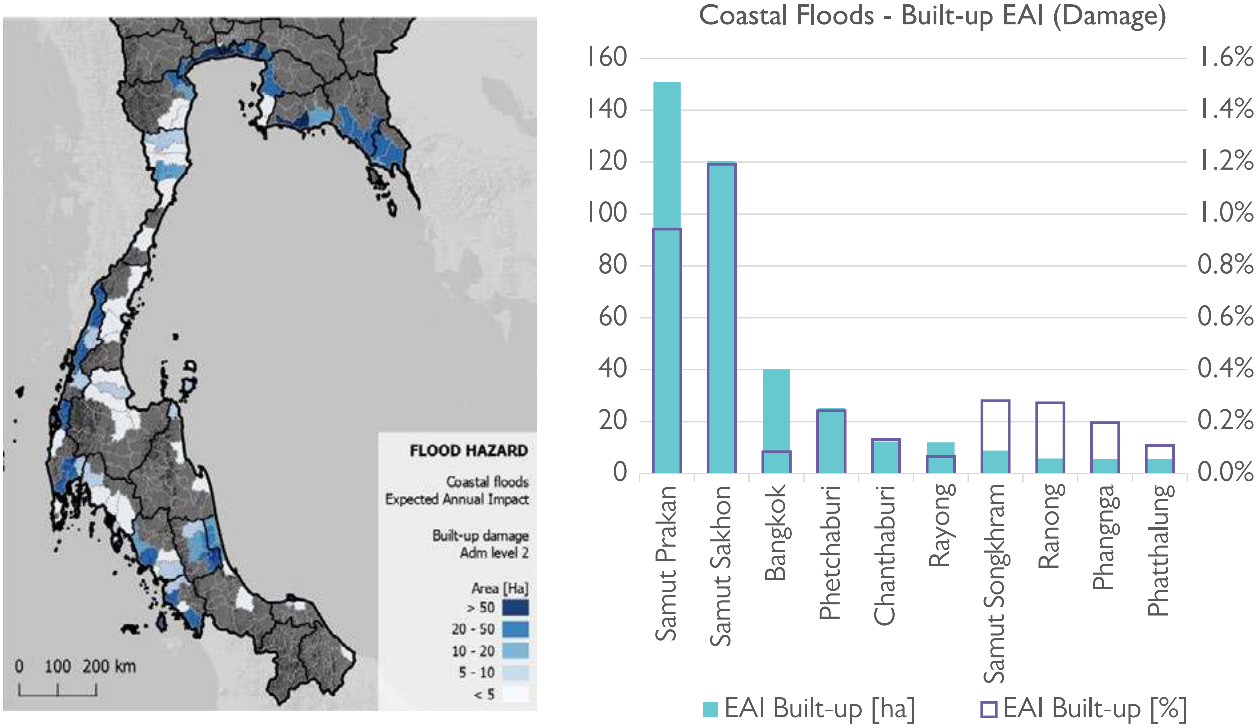
The costs to Thailand's economy of future impacts of sea level rise and coastal erosion are moderate but will continue to increase. The figures in Table 2.3 are estimated using damage increases that occur despite dikes being built, according to Lincke and Hinkel (2018). The difference between the scenarios is limited; under all scenarios, an increase in costs of around $6 billion is expected.

Figure 2.9. Expected annual impact of coastal floods - Population mortality



Source: Fathom Global Models, FATHOMv2

Figure 2.10. Expected annual impact of coastal floods on built-up damage



Source: Fathom Global Models, FATHOMv2

Table 2.3. Costs of sea level rise (SLR) and coastal erosion in 2050, USDm at 2010 prices, compared to 2015

	RCP2.6	RCP4.5	RCP6.0	RCP8.5
SLR and erosion	6696.2	5915.2	5603.8	6379.4

Source: Staff calculations derived from Cheung et al. (2010)

2.4.2. Drought and heat stress

Drought poses a significant concern to Thailand, where most of the agricultural production is concentrated in the central and eastern plains. Thailand has experienced several drought events, including in 1995-1996 and 2005-2006, that had a profound impact on key crop production, leading to food scarcity and economic challenges for farmers (Figure 2.11). The impact of drought on crops can vary widely, depending on factors such as the severity and duration of the drought, the region in question, and the specific water requirements of the crops involved. Additionally, the effects on crops and the broader agricultural sector can be influenced by agricultural practices, water management strategies, and government policies.

Figure 2.11. Frequency of drought hazard

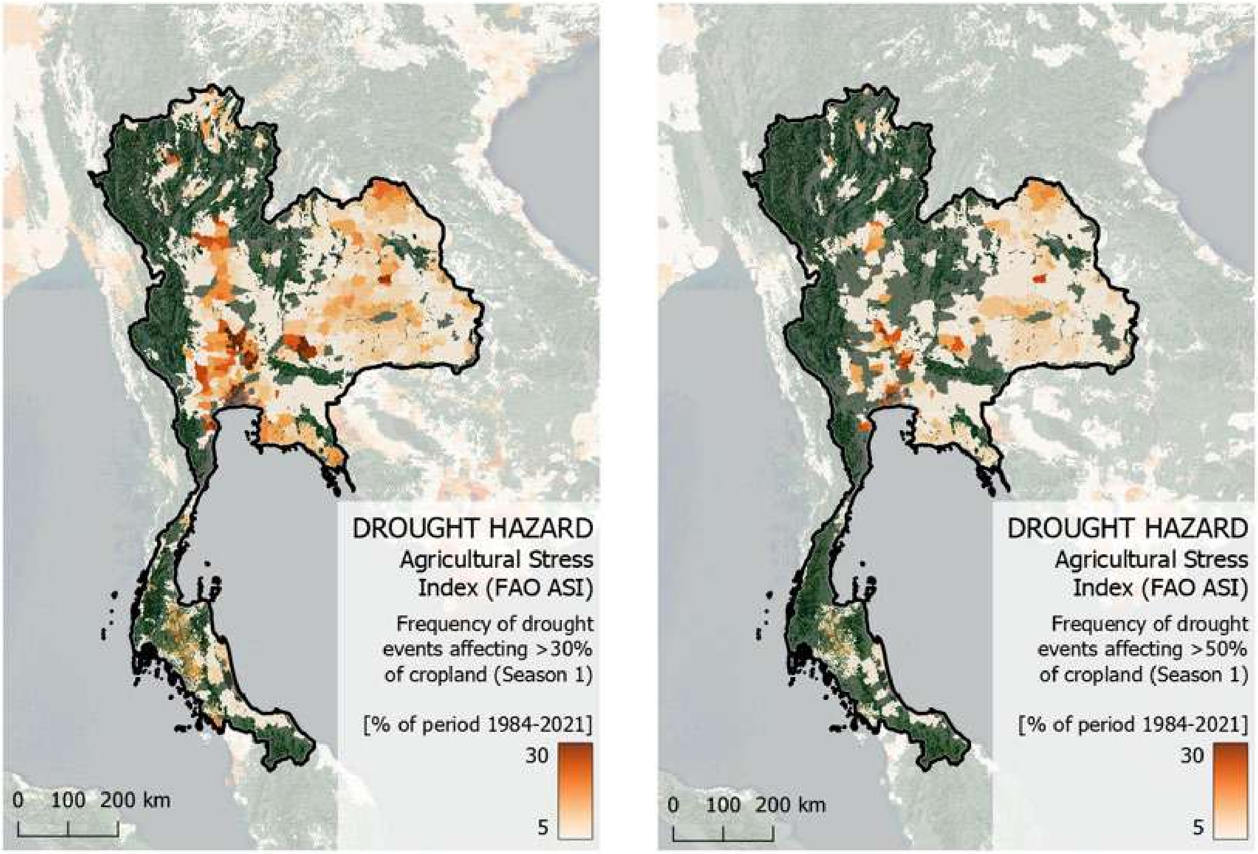
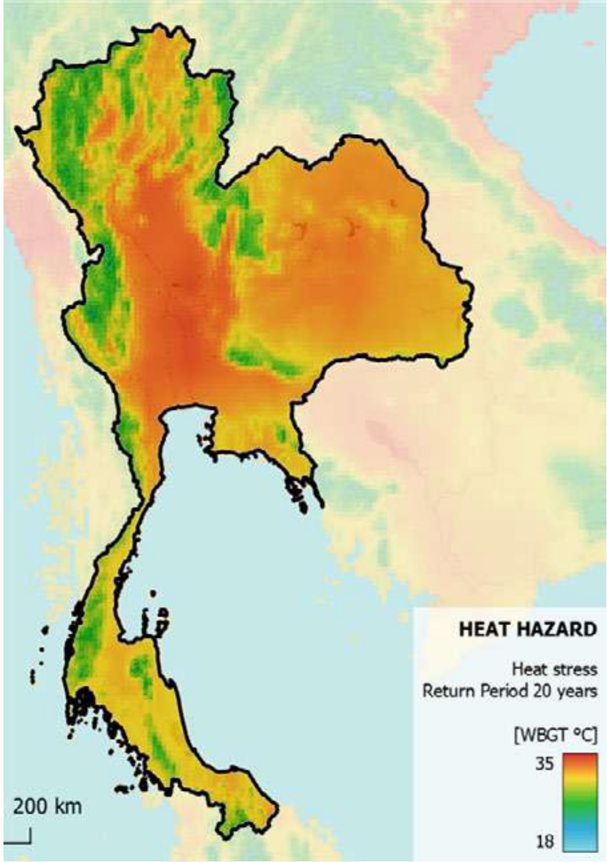


Figure 2.12. Heat Stress for a 20-year return period (WBGT C)



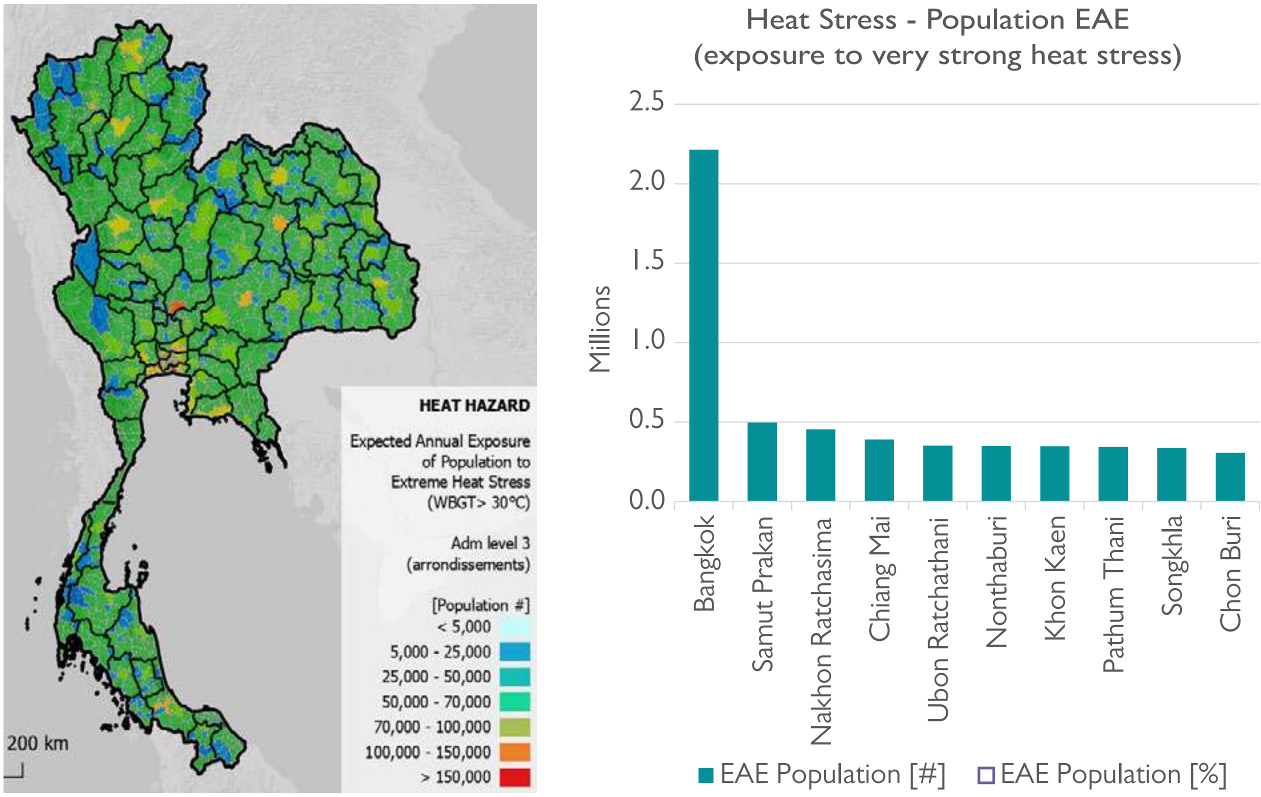
Source: Fathom Global Models, FATHOMv2

Thailand experiences exposure to high annual average temperatures, which can rise above 32°C during the dry season, particularly in the central plain. To assess the probability of heat stress, one of the key measures used is the Wet-Bulb Globe Temperature (WBGT), which considers both temperature and humidity — critical factors in determining heat stress. In the analysis conducted, three return periods for heat events were considered: once every five, 20, and 100 years. Figure 2.12 illustrates the modeled maximum heat for the 20- year return period scenario. In this scenario, WBGT values exceeding 32°C are commonly observed in the central and eastern plains, which includes major metropolitan areas like Bangkok and other significant urban centers.

Population exposure to heat stress is substantial. Figure 2.13 illustrates the annual expected population exposure, which combines all the hazard probability scenarios. In this combined assessment, more than 2 million people residing in Bangkok, along with several hundred thousand individuals living in densely populated urban centers situated in the Chao Phraya basin, face annual exposure to severe heat stress. This exposure has significant implications of heat stress for public health and the economy.

Climate change already impacts outdoor labor productivity; losses could double by 2050. Climate change is already reducing labor productivity in the agriculture and construction sectors by 4.5 percent. The loss of productivity will continue to grow in all climate scenarios because of increased temperature, with work becoming difficult on days of extreme heat and humidity. Impacts range from 6.5 percent loss (RCP2.6) to 9.6 percent loss (RCP8.5) by 2050 (Table 2.4). Although the figures appear substantial, the macroeconomic impact of these productivity losses in the modeled scenarios appears modest because half the impact is already included in the historical data. Indoor labor productivity will be affected by much less because of air conditioning, but the annual costs of installing and running cooling systems could reach $11-17 billion annually by 2050 (see below).

Figure 2.13. Annual Population exposure to heat stress



Source: Fathom Global Models, FATHOMv2

Table 2.4. Economic cost from loss of outdoor labor productivity and indoor cooling in 2050, USDm at 2010 prices, compared to 2015

	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Outdoor costs	6.4	7.8	7.3	9.6
Cooling costs	11590.7	13764.0	13039.6	16661.7

Source: Climate Analytics

Heat stress will also affect the oceans and losses from fishing will be substantial in all climate scenarios, far exceeding those from agriculture. The data in Table 2.5 for loss of crop production in RCP8.5 are taken from IFPRI (2019), with a quadratic function used to estimate values for other RCPs and over time. The total agricultural impacts range from $2.9 billion in RCP2.6 to $5.4 billion in RCP8.5. The scale of impact does not vary much between the RCPs for rice, with most of the variation in impacts between the RCPs occurring in other crops. However, these impacts are by far exceeded by potential loss of fishing production. The fishing impacts are estimated from O´Reilly et al. (2003) and Cheung et al. (2010) and cover both inland and marine fisheries. The figures for RCP4.5 are used and applied to other RCPs based on temperature differentials. The results show that up to $26.2 billion of production value is at risk, by far exceeding potential impacts from lost crop production.

Table 2.5. Loss of production in 2050, USDm at 2010 prices, compared to 2015

	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Rice	1635.1	1941.7	1839.5	2350.5
Other crops	1276.6	1835.2	2221.5	2838.6
Fishing	18256.1	21679.1	20538.1	26243.1

Source: Staff calculations derived from IFPRI (2019), O´Reilly et al. (2003) and Cheung et al. (2010)

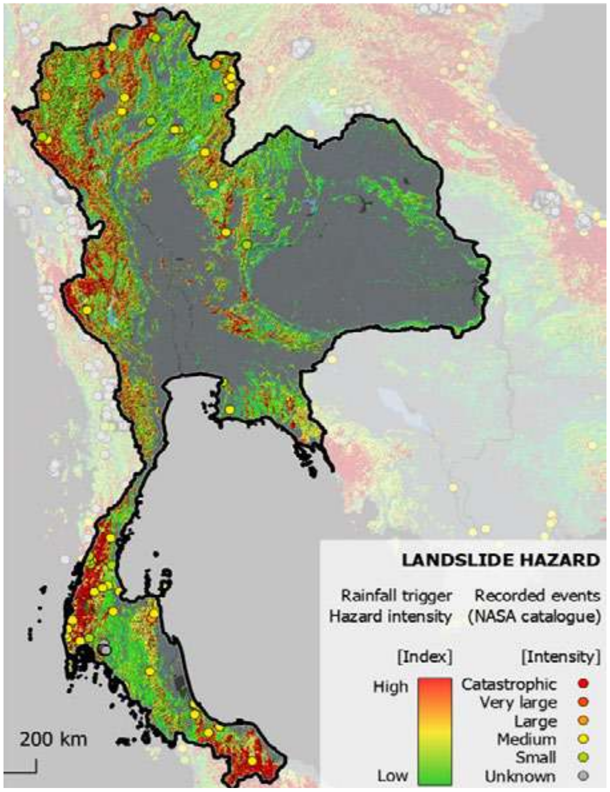
Other impact channels suggest substantial costs to Thailand across all the climate scenarios. Estimates of the costs of cooling are derived from the DARA (2012) global study and projections of cooling requirements in Baumert and Selman (2003). The economic valuations draw on a wide range of engineering and economic literature, and local energy prices are used. Data for RCP4.5 are extrapolated linearly following DARA (2012) to give estimates for the other RCPs. Substantial costs are estimated for all scenarios, with a range of $11.6 billion in RCP2.6 to $16.7 billion in RCP8.5. Losses from tourism are expected to be smaller, with a similar relative variation between climate scenarios. Data are taken from Hamilton et al (2005) and Roson and Sartori (2016).

2.4.3. Other disasters

The intensity of landslides can be magnified by factors such as land use changes and deforestation. Data from the NASA Global Landslide Catalogue for the period 2007-2022 has recorded a limited number of landslide events. Among these events, eight are reported as significant in size, occurring primarily in the rugged terrain of the northeastern and southern regions of the country (Figure 2.13). Because of a lack of data, landslides are not included in the modeling in this report.

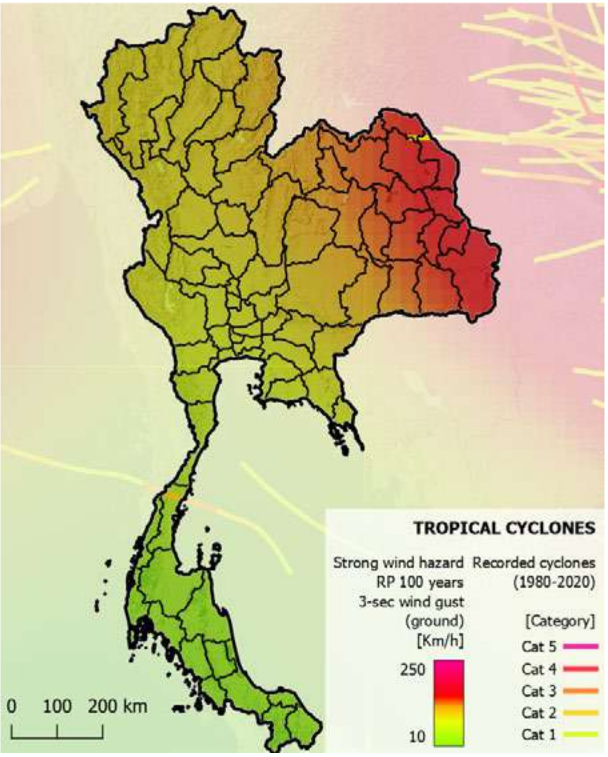
Thailand is only marginally affected by tropical cyclones. Often, cyclone events in the southwest Pacific do not reach the country, or they only partially affect the northeastern regions, including Isan and Northern Thailand. A combination of the IBTrACS v4 database (Kenneth et al., 2010) and GAR 2015 probabilistic wind hazard layers can be used to identify the regions most exposed to hazardous wind intensity. Figure 2.14 below illustrates the areas most exposed to hazardous wind intensity, and Figure 2.15 depicts the potential impact on built-up areas. The impacts of cyclones are included in the modeling in this report but have only a small effect on results.

Figure 2.14. Rainfall-triggered Landslide Hazard Index for Thailand



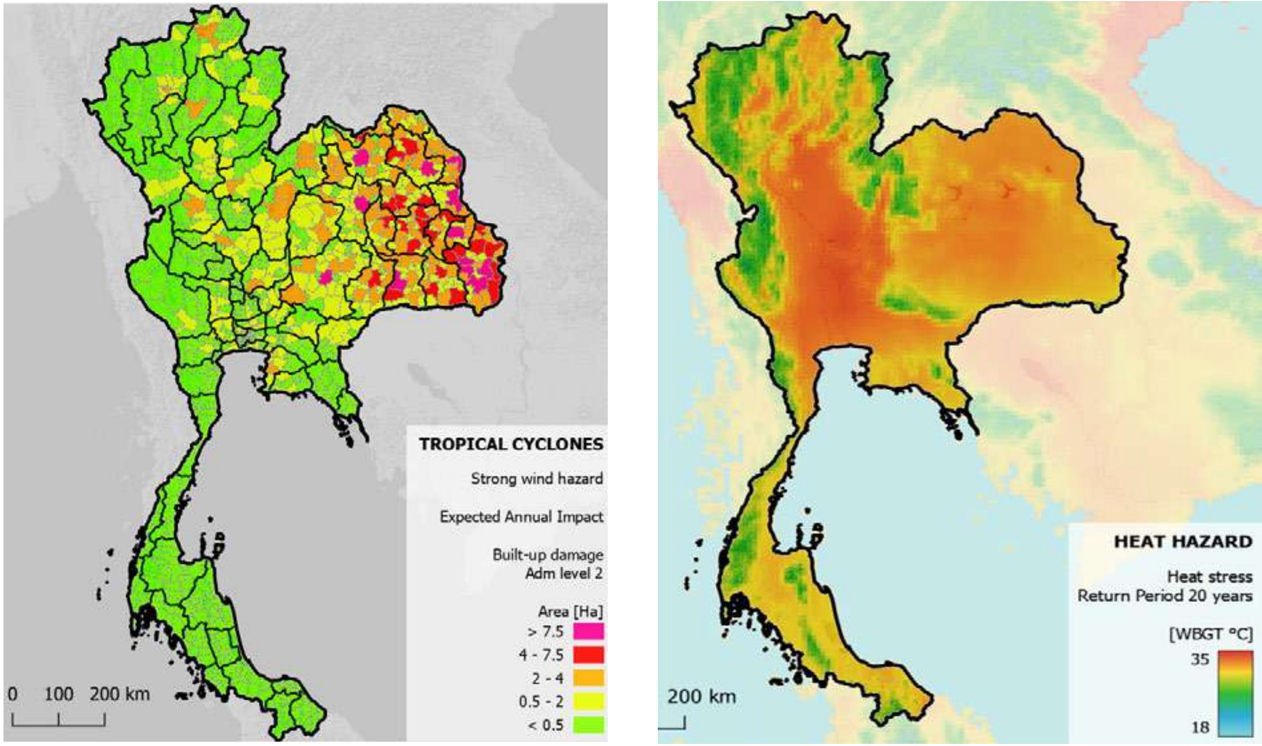
Source: ARUP 2016

Figure 2.15. Strong cyclone hazards



Source: Global Assessment Report (GAR) 2015 and IBTrACS v4 database

Figure 2.16. Expected Annual Impact over built-up land



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3

TRANSITIONING TO A BIO-CIRCULAR-GREEN ECONOMY

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3. TRANSITIONING TO A BIO-CIRCULAR-GREEN ECONOMY

3.1. METHODOLOGY

Transitioning to a BCG+ economy would require substantial economic reform across all major sectors of the economy. As with any transition, there will be winners and losers from the reforms. This chapter explores the effects of possible BCG+ reforms across sectors and identifies potential outcomes at the macro-economic level. It uses a set of sectoral macro-economic modeling tools to quantify impacts where feasible.

The quantitative analysis in this chapter is based on three modeling tools, which are described briefly below. The models have different purposes and levels of detail; Table 3.1 describes how they are applied to the different scenarios.

Table 3.1. How the models in this chapter are applied

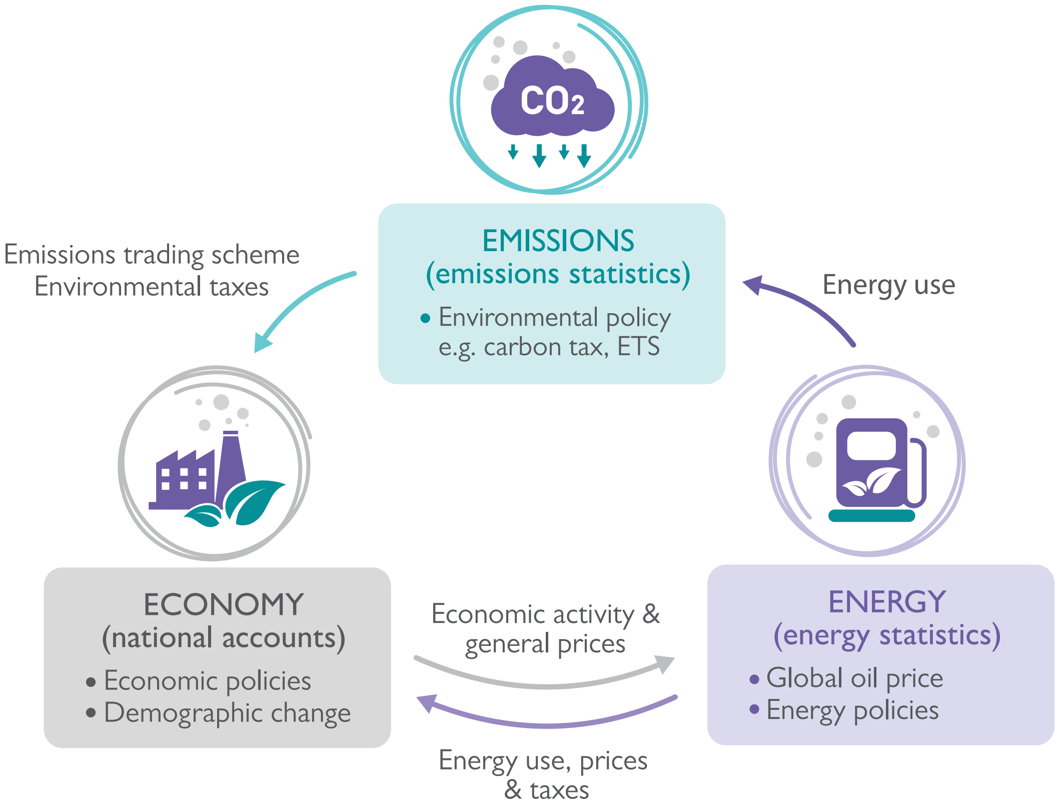
Topic area	Models applied
Impacts of climate change	E3-Thailand, input-output model
Adaptation measures	E3-Thailand
Reducing emissions in Thailand	E3-Thailand, FTT models
Circular economy	E3-Thailand

3.1.1. E3-Thailand Model

The E3-Thailand model (E3M) is a comprehensive macro-econometric model designed for assessing the macro-economic impacts of climate change mitigation and adaptation policies. It was originally developed to evaluate the impacts of carbon pricing instruments in the context of Thailand's NDC targets and provides a full macro-economic framework. The model includes a detailed sectoral disaggregation, with 42 economic sectors, 28 consumer spending categories, and 24 users of five different energy carriers. This level of granularity makes it well-suited for assessing the economic impacts of broader sustainability policies. The model integrates the Thai economy, energy consumption, and emissions into a single modeling system, allowing for a comprehensive analysis of different policy scenarios and their potential effects on the economy, energy sector, and GHG emissions (see Figure 3.1).

E3M is based on a demand-driven framework, in contrast to Computable General Equilibrium (CGE) models. While both approaches share the common objective of analyzing policy impacts on the economy, E3M stands out by incorporating empirical data and utilizing econometric techniques. This allows the model to capture realistically the complexity of the economy, accounting for factors like imperfect knowledge, bounded rationality, and flexible markets (Mercure et al., 2016). By reflecting observed behavior, E3M provides an authentic representation of the economy, considering both the efficiency of resource allocation and the impact of policies on aggregate demand while encompassing stimuli or austerity effects (Mercure et al., 2019; Pollitt and Mercure, 2018).

Figure 3.1. Overall structure of the E3-Thailand model



3.1.2. Input-output analysis

The macro-economic modeling in E3M is supported by a flexible input-output framework. While E3M already incorporates an input-output (IO) core, a separate IO analysis was conducted to evaluate potential supply-chain constraints. Like E3M, the IO analysis within this chapter considers multiplier effects between outputs and inputs, such as the interdependence of car and engine production. However, the IO analysis also explores bottleneck supply-chain effects in the reverse direction, anticipating scenarios in which a decline in engine production affects car production. These supply-chain effects are inherently uncertain because of various behavioral responses that could prevent bottlenecks (Hallegatte, 2014). Companies, for example, might adapt by switching suppliers, importing crucial components, or maintaining stocks of key inputs to mitigate supply disruptions. As a result, the IO analysis presents a range of potential impacts, contingent on different assumptions regarding preparedness in managing disruptions to their supply chains.

3.1.3. Future Technology Transformations (FTT) model

The FTT models are designed to assess the diffusion paths of low-carbon technologies. The models are based on the spread of information and the interaction between adopters and non-adopters (Mercure, 2012). They draw a nuanced parallel, likening the diffusion process to the intricate dynamics observed in the spread of an infectious disease. This comparison delves into the multi-faceted aspects of both phenomena, emphasizing not only their propagation through a population but also the complex interplay of factors influencing their trajectories. The model assumes that contact with other adopters and exposure to information on the innovation leads to potential adoption. The flow of new adopters is a function of the stock of existing adopters. As the stock of existing adopters increases, the risk of "contagion" also increases, resulting in an exponential rise in the flow of new adopters. However, as the stock approaches the total number of potential adopters, the flow gradually decreases and eventually becomes zero. The diffusion of the innovation follows a symmetric S-shaped function over time. In this chapter, FTT modeling is used to assess the potential adoption of electric vehicles (EVs) in Thailand (Mercure et al., 2018).

3.2. DESIGN OF THE MODELING SCENARIOS

The scenarios in this chapter assess climate impacts, possible adaptation responses to these impacts, measures to reduce GHG emissions, and policies to improve the circularity of Thailand's economy. The first scenario assesses the potential economic impacts of climate change in Thailand, based on the results of the analysis in Section 2.4. The second scenario evaluates the effects of adaptation measures aimed at reducing these impacts. The third scenario considers measures for Thailand to reduce its GHG emissions. Lastly, the analysis extends to include a scenario based on a move toward a circular economy. While the climate impact and adaptation scenarios are modeled up to 2050 because impacts grow over time, the scenarios in which Thailand reduces its emissions and adopts a circular economy are assessed to a 2040 timeframe, reflecting more the interests of policymakers. Findings are compared with a baseline case that incorporates existing policies without additional climate policies and with no climate impacts beyond those seen today. The baseline extrapolates historical data, including current Thai policies but excluding supplementary climate policies. Population growth aligns with the UN's constant fertility scenario, and GDP growth is projected slightly below 3 percent per annum. The sectoral mix in Thailand follows historical trends, with the share of agriculture and manufacturing in GDP gradually decreasing and the services sector's share increasing.

3.2.1. Assessing the impacts of climate change in Thailand

The modeled scenario incorporates the analysis from Chapter 2 and further assesses the risk from large flood events. Chapter 2 outlines Thailand's current climate vulnerabilities and attempts to quantify the future impacts of climate change. These results are fed into E3M to obtain estimates of economy-wide impacts including indirect effects, as well as impacts on jobs and other macro-economic indicators (Table 3.2); agriculture is impacted through multiple channels. The limitations in data and methodology to estimate climate impacts are acknowledged, so the analysis is supplemented by a separate scenario that assesses the impacts of a large flood in 2030. The modeled scenarios give a range of outcomes that cover potential worst-case impacts in a single year, but are grounded in more widely available data.

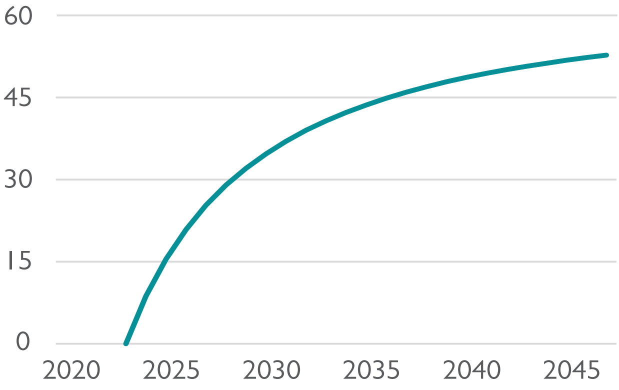
Table 3.2. How the impact channels are represented in E3M

Impact Channel	How entered to model
Loss of labor productivity: Agriculture, forestry, and fish; Construction	Production loss in the agriculture and construction sectors
River flood damage	Loss of production in all sectors
Tropical cyclones	Loss of production in all sectors
Losses in agriculture: rice Losses in agriculture: other crops	Loss of production in agriculture
Losses from fisheries	Loss of production in agriculture
Additional costs of cooling	Reduced household expenditure to compensate cooling costs
Losses in tourism	Reduced demand for hotels and catering
Sea level rise and coastal erosion	Loss of production in agriculture (because it is agricultural land lost)

3.2.2. Assessing the potential to adapt to climate change in Thailand

There is substantial uncertainty about the potential to adapt to climate change in Thailand, but adaptation investment opportunities that offer a high return are likely. Thailand is not unique in having limited data on potential climate adaptation measures (both on potential costs and damages averted). However, the extensive exposure of Thailand to floods and other climate events means that there are likely to be adaptation options with potentially high returns.

Figure 3.2. Share of damages avoided, %



Source: ARUP 2016

In this chapter, we use data from the World Bank's *Unbreakable* and *Lifelines* reports (Hallegatte et al., 2019) to estimate adaptation costs and avoided damages. Although carried out at a relatively aggregate level, and focusing on adaptation in infrastructure, the data suggest that damages could be reduced substantially at a relatively low financial cost. Some of the adaptation measures will have almost no direct cost, for example enforcing existing building regulations or preventing new building on flood plains. Others, such as climate-proofing large-scale new investments, could have larger costs.

Both the investment costs and the avoided damages are entered into E3M to give an overall estimate of economic impact. The adaptation measures only apply to new infrastructure, so the share of damages reduced depends on the proportion of new infrastructure in the capital stock. Figure 3.2 shows the share of avoided damages in the adaptation scenario.

3.2.3. Assessing measures to reduce emissions within Thailand

As indicated earlier, Thailand faces the imperative to consolidate and augment its existing policies to fulfill its current climate targets. The trajectory of Thailand's emissions in the post-economic recovery from COVID-19 remains uncertain. While emission levels are anticipated to be significantly lower than the baseline values outlined in Thailand's NDC, additional efforts may be necessary to achieve emissions reductions in line with existing targets, especially if the 2030 goal is elevated. Hence, it is crucial to explore how emissions can be further reduced by identifying sectors and employing various policy instruments.

Affecting substantial emissions reductions in Thailand will require a diverse set of policies. The climate change mitigation policy analysis in the scenario involves two distinct modeling exercises. First, utilizing the E3M, the focus is on assessing the potential impacts of carbon pricing, a topic aligned with current government interests. The carbon price is applied to all energy-related CO_2 emissions in the economy. Revenues from the carbon tax are split equally to reduce income and employers' labor taxes so that the overall scenario is revenue neutral. Second, a detailed examination is conducted on the measures required to meet Thailand's ambitious targets for the adoption of EVs. This exercise, using the FTT technology diffusion model, underscores the significance of policy interaction in addressing issues related to technological change. The main scenario tested involves a combination of policies, including substantial public investments in EV infrastructure, electrification of the public fleet (scheduled for 2025), support for the electrification of taxis, and incentives for EV purchases.[2]

3.2.4. Assessing the move to a circular economy

Moving beyond the scope of climate change, the transition towards a circular economy is pivotal for long-term economic sustainability. A circular economy revolves around the perpetual reuse of resources, contrasting with the traditional linear model of extraction, consumption, and disposal. In a world constrained by finite mineral resources, the circular economy stands out as the truly sustainable approach. Key principles involve not only recycling but also product reuse and adjustments in consumption patterns to minimize material usage. For a country like Thailand that is heavily reliant on imported raw materials, embracing the circular economy offers economic security benefits, making it an integral aspect of the Bio-Circular-Green economy.

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[2] The modeled scenario includes mandated electrification of 5 percent of the vehicle fleet (including taxis and public vehicles), plus building infrastructure for another 5 percent. Fuel taxes equivalent to \$25/tCO_2 (in addition to existing duties) are also added.

The circular economy scenario amalgamates a spectrum of policies aiming to instigate reforms across various sectors of the economy. While interpretations of the circular economy vary, the scenario incorporates elements aligned with either already announced policies/targets or those considered achievable for Thailand (Table 3.3). The scenario's targets and quantifications stem from sectoral analyses within the report, externally published literature, and expert judgments from the report team (World Bank, 2022). In E3M, most scenario inputs manifest as changes in input-output co-efficients, dictating transaction volumes between different economic sectors. For example, a measure to recycle steel would alter the quantity of inputs from non-energy mining to basic metals while increasing the contribution from the waste management sector to basic metals. Changes in final consumption, such as clothing and equipment, are factored into household budget share calculations, with model parameters determining the allocation of remaining income for other purchases. The scenario results intentionally exclude any initial investment effects due to their inherent uncertainty. Consequently, these outcomes should be regarded as long-term results. The pivotal question of how to finance the requisite investments and whether they would potentially impact other economic activities in Thailand remains a crucial consideration for the future.

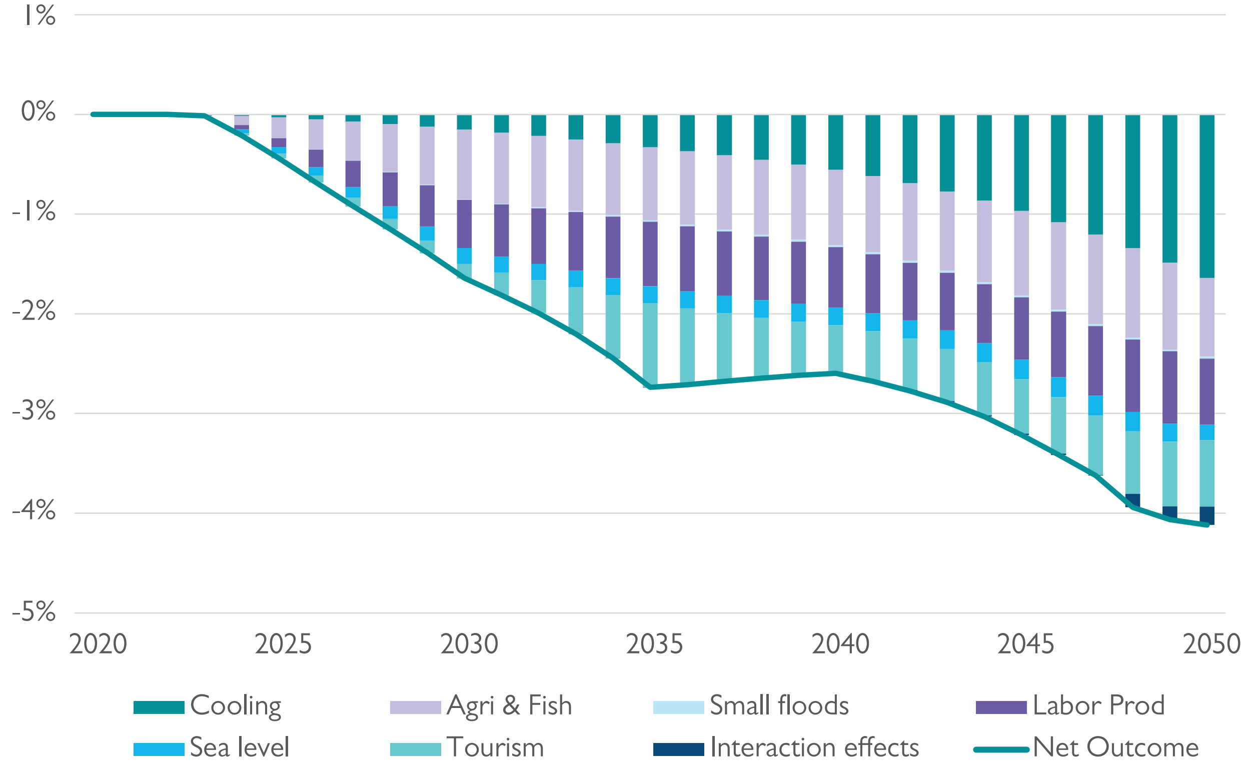
Table 3.3. Circular economy policies in the modeled scenario, targets met by 2030

Measure	Description
Eco-design initiative	Manufacturing sectors reduce material input by 10% (excluding specific interventions described below).
Reduced food waste	Food waste in supply chains falls from 30% to 10%. Remaining production is exported.
Plastic recycling	The share of plastics that are reused or recycled increases to 55%. It is noted that Thailand has a target of 100% reusable plastics by 2027 in its national roadmap on plastic waste management.
Increased product lifetimes	The lifetimes of clothes and durable goods is extended by 10%.
Sharing economy	Purchases of vehicles falls by 3%, clothing by 6%, and durable goods by 5% (European Commission, 2018).
Textile recycling	Consumption of chemical inputs (e.g. polyester) by textiles reduced by 25%.
Recycled steel	The share of recycled steel increases to 40%.
Reduced cement use	The overall volume of cement used by the construction sector falls by 20%. Half of this reduction is replaced by recovered materials. A quarter is replaced by wood and a small share from agricultural residues. The remaining reductions come from efficiency gains.
Electric vehicles	The penetration rate of EVs in the fleet reaches 30%, matching results in Section 3.5.

3.3. THE IMPACTS OF CLIMATE CHANGE IN THAILAND

The data gathered in Section 2.4 suggest that, although climate change could have limited impacts on GDP, the risk of catastrophic events has increased. In this bottom-up modeling exercise, estimates of climate damages from academic literature, often presented as "average annual losses," are aggregated. The model adds indirect and multiplier effects to get a whole-economy estimate of losses. Figure 3.3 depicts the outcomes of this modeling exercise, revealing relatively modest impacts reflected in the model results, with GDP losses reaching only 2.5 percent by 2050. Initially, the most significant impacts stem from the loss of agricultural and fishing capacity (with a high emphasis on fishing), with cooling costs gradually becoming more important.

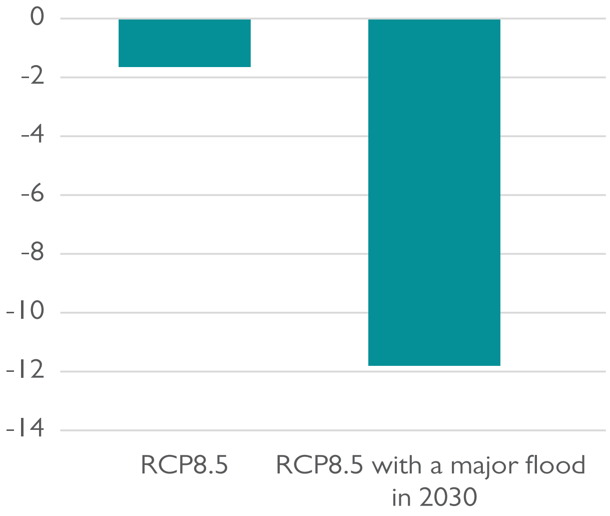
Figure 3.3. Impact of different categories of climate damages on GDP (RCP8.5) (% from baseline with no climate change)



Source: World Bank Staff estimates based on E3-Thailand model

However, it is crucial to approach the interpretation of these small impacts with caution and not conclude that they indicate minimal climate risk in Thailand. It is important to recognize that analyses of expected losses and risks are addressing different questions. The primary concern is the risk and loss of welfare resulting from extreme weather events, particularly floods. While the modeled impacts might have limited long-term effects on GDP if all damaged capital stock is repaired or replaced, there could be a substantial short-term loss of welfare and increases in private and public debts associated with rebuilding lost capital.

Figure 3.4. Impact of a major flood on GDP in the year the flood occurs (here 2030)



Note: percentage of change in GDP considering all climate damages in Section for RCP8.5 and RCP8.5 with the additional 2030 flood described above.
Source: World Bank Staff estimates based on E3-Thailand model

The analysis can therefore be enhanced by incorporating a distinct scenario featuring a significant flood event. The scenario assesses what would happen if a large flood occurred in 2030. The likelihood of this flood occurring in a given year is comparable to that of the 2011 floods, i.e., approximately 1 in 50. However, the severity of the 2030 flood exceeds that of 2011, attributed to a confluence of economic development and climate change, thereby heightening its potential impact. Estimates derived from the Aqueduct Floods model[3] suggest that a similar flood in 2030 could yield double the economic repercussions of the 2011 event. The outcomes from the E3M match this finding, revealing a potential production loss of nearly 10 percent (Figure 3.4). The enduring consequences of such a flood hinge on the extent of infrastructure reconstruction. Repeated flood occurrences could lead to slower rebuilding rates, resulting in more pronounced and lasting negative impacts on economic growth.

Climate change is poised to have the most significant impact on Thailand's agriculture and fishing sectors. To assess distributional outcomes, the study examined 42 different sectors, consolidating them into eight broad economic categories (Figure 3.5). Each sector's performance was compared against the baseline, providing insights into the extent of change induced by various factors or interventions. This approach allows for a sector-specific analysis of the variations from the baseline, offering a detailed perspective on the potential impacts of different scenarios on each economic sector. The modeling clearly indicates that the agriculture and fishing sectors are exceptionally exposed to climate change, a vulnerability exacerbated by Thailand's substantial local fishing industry and shrimp farming. While these findings align with global patterns, Thailand faces a heightened risk due to its unique economic landscape.

Production losses in agriculture and fishing could impact vulnerable populations and increase poverty. The implications of substantial and sustained production losses in agriculture and fishing are profound because many of the lowest-income households in Thailand depend on these sectors for their livelihoods. This vulnerability has the potential to significantly impact poverty rates in the country, underscoring the urgent need for targeted strategies to address the specific challenges faced by these key sectors.

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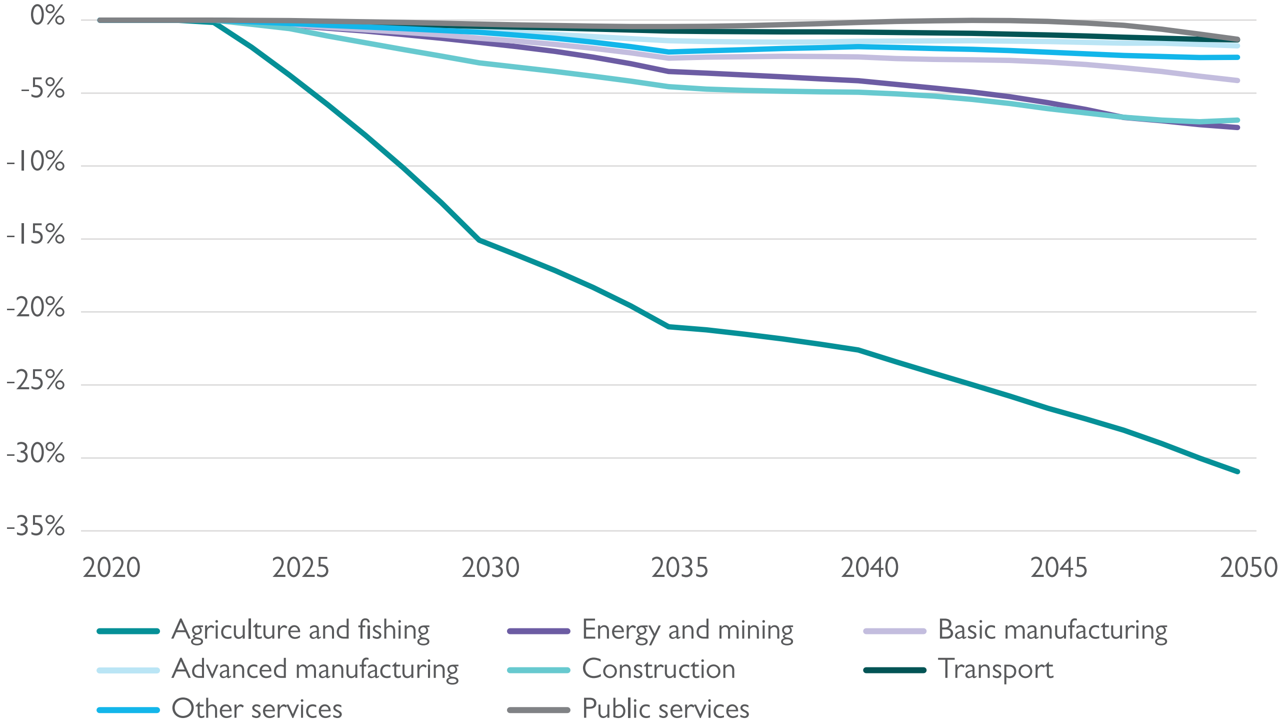
[3] https://www.wri.org/aqueduct/tools

Figure 3.5. Percentage change from baseline in each sector's production



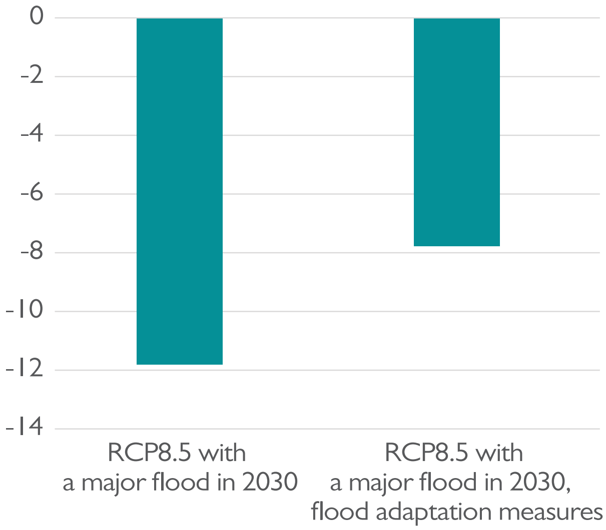
Source: World Bank Staff estimates based on E3-Thailand model

3.4. ADAPTING TO CLIMATE-INDUCED FLOODS

Implementing measures to adapt to climate change could significantly reduce the damages caused by floods, particularly through flood mitigation strategies. These efforts could lead to a decrease in the GDP impact of a major flood in 2030 by four percentage points (Figure 3.6). The focus should be on safeguarding new infrastructure by strategic placement, avoiding flood-prone areas when possible, and enhancing resilience to climate events. However, adapting existing infrastructure presents challenges, and human vulnerabilities will persist, particularly in the face of other climate change impacts such as shifts in fishing patterns and increased heat stress for outdoor workers. As a result, adaptation is recognized as a partial solution to the overarching climate challenge. While efforts to adjust and enhance infrastructure resilience are essential, it is crucial to acknowledge the limitations in addressing all aspects of the complex and multifaceted challenges posed by climate change. Recognizing the partial nature of adaptation underscores the need for comprehensive strategies that encompass mitigation, resilience-building, and broader climate policies to tackle effectively the complexities of climate change.

While the costs associated with a flood prevention program need not be excessively high if managed carefully, there are effective and economic "soft" climate adaptation measures available. These measures encompass the development of early warning systems, the enforcement of building regulations, and a strategic approach to construction in flood-prone areas. In Thailand, there are potential low-cost options to enhance infrastructure, exemplified by the estimated cost of protecting against flood damage in Bangkok, reaching up to THB 56.9 billion (equivalent to 0.4 percent of GDP in 2020) according to a 2010 study. Despite being one-time investments, these endeavors provide protection against events expected to become more frequent due to climate change.

Figure 3.6. Impact of a major flood in 2030 on GDP (% from baseline) with and without flood protection measures



Source: World Bank Staff estimates based on E3-Thailand model

The easiest adaptation measures will be protecting new infrastructure. Insights from the World Bank's *Lifelines* report suggest a compelling proposition that climate damages to transport infrastructure could be significantly mitigated, achieving a 70 percent reduction at a modest cost of only 1.2 percent of the total capital investment. However, the success of building resilience relies heavily on the careful identification and focused targeting of infrastructure in need of protection. If not handled with precision, costs could quintuple. In broader terms, top-down estimates project that the overall expenses associated with adapting to climate change in Thailand could be at least 1.6 percent of GDP.

3.5. REDUCING EMISSIONS WITHIN THAILAND

Implementing carbon pricing mechanisms could stabilize emission levels in Thailand, but achieving long-term emission reductions necessitates additional policy measures. Figure 3.7 illustrates two scenarios regarding carbon prices in Thailand, introduced in the form of a tax and applied to CO_2 emissions across all economic sectors with rates gradually increasing over time. Both scenarios start with modest tax rates that increase to \$20/tCO_2 in the NDC scenario, and \$40/tCO_2 in the Ambitious case. While both scenarios reduce emissions, their adequacy in meeting Thailand's current NDC emission reduction target depends on the post-COVID baseline trajectory of emissions (including non-CO_2 emissions), which remains uncertain. Notably, the carbon taxes alone are insufficient for achieving sustained, long-term emission reductions.

Achieving deep emission reductions to meet Thailand's carbon neutrality target will require a combination of policies. While carbon pricing creates incentives to change energy user behavior, its effectiveness depends on the availability of technology options. The possibilities of carbon prices in the form of either carbon taxes or emission trading schemes has previously been discussed in Thailand. Figure 3.8 presents a summary of compatibility between carbon taxes and key emitting

Figure 3.7. Potential decarbonization scenarios for Thailand

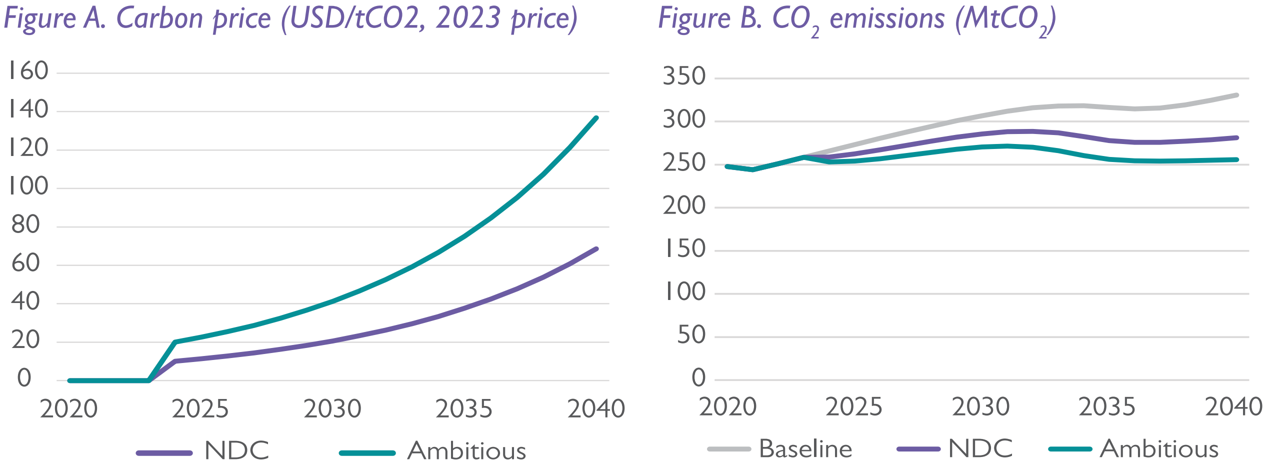


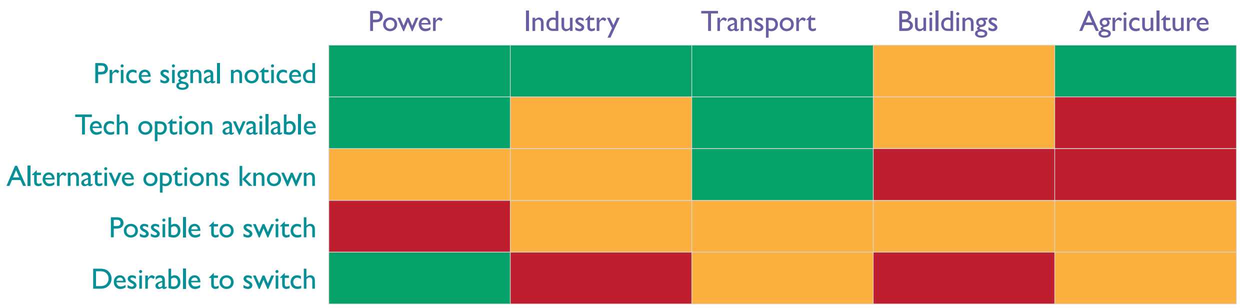
Figure A. Carbon price (USD/tCO2, 2023 price)

Figure B. CO_2 emissions ($MtCO_2$)

Source: World Bank Staff estimates based on E3-Thailand model

sectors in Thailand. Red boxes highlight potential barriers to behavior change, including the possibility that energy users may not perceive the price increase from carbon taxes, technology options may be insufficient, knowledge gaps may exist, or there could be regulatory or capability barriers to switching. Additionally, the cost of behavioral change may be prohibitive, even with a carbon tax as depicted in Figure 3.8. Notably, the power and transport sectors emerge as potentially amenable to carbon taxes, but effective price incentives in the power sector would require market reform and additional infrastructure is required in transport.

Figure 3.8. How the main sectors meet the criteria for effective carbon pricing



	Power	Industry	Transport	Buildings	Agriculture
Price signal noticed	🟩	🟩	🟩	🟧	🟩
Tech option available	🟩	🟧	🟩	🟧	🟥
Alternative options known	🟧	🟧	🟩	🟥	🟥
Possible to switch	🟥	🟧	🟧	🟧	🟧
Desirable to switch	🟩	🟥	🟧	🟥	🟧

Note: Green cells indicate good compatibility and red cells potential impediments. Orange cells indicate either sectoral heterogeneity or partial compatibility.
Source: World Bank Staff estimates

Carbon taxes have the potential to increase GDP and employment if the revenues are utilized effectively. Figure 3.9 displays the results from model simulations for the same scenarios as presented in Figure 3.7. In these simulations, the revenues generated from carbon taxes are employed to reduce both income and employers' labor tax rates. Model results suggest a slight increase in the levels of both GDP and employment compared to the baseline scenario. The GDP increase is attributed to two types of demand stimulus. First, there is additional investment in low-carbon equipment, particularly in the power sector, despite the limited effectiveness of the carbon tax. This is because the power sector becomes more capital-intensive and less energy intensive. This effect is more noticeable in the short term, funded by higher debts that must be repaid over the equipment's lifetime. Second, there is a positive shift in Thailand's trade balance. The consumption of imported fossil fuel decreases, while domestic fossil fuel production may be sold on global markets, thereby boosting exports. Importantly, Thailand's other exports are generally not carbon-intensive, limiting any loss of competitiveness from higher energy costs.

Figure 3.9. GDP and Employment impact of carbon taxes

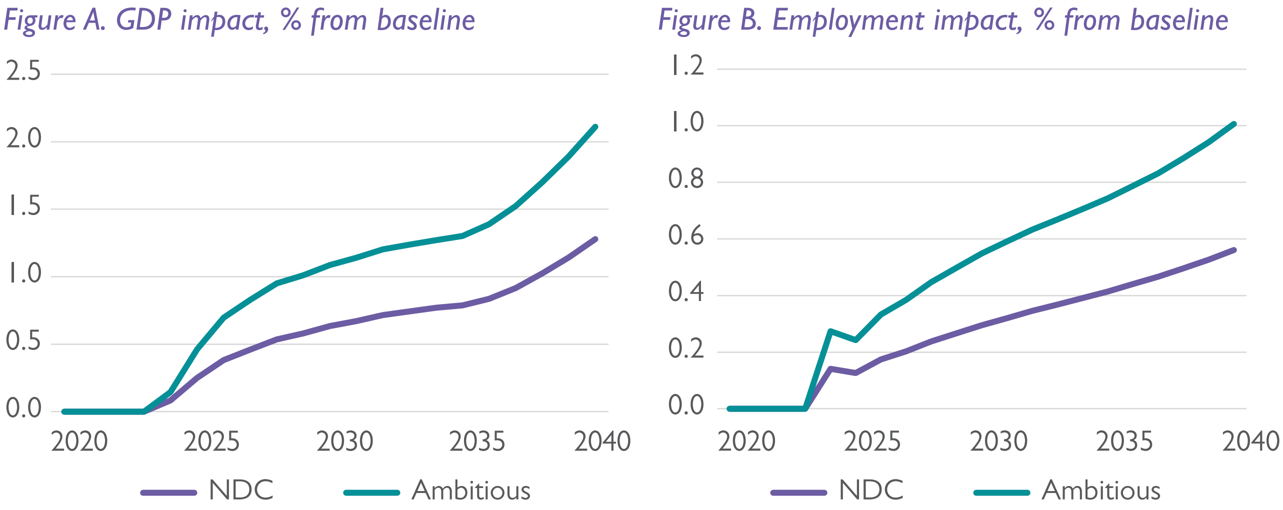


Figure A. GDP impact, % from baseline

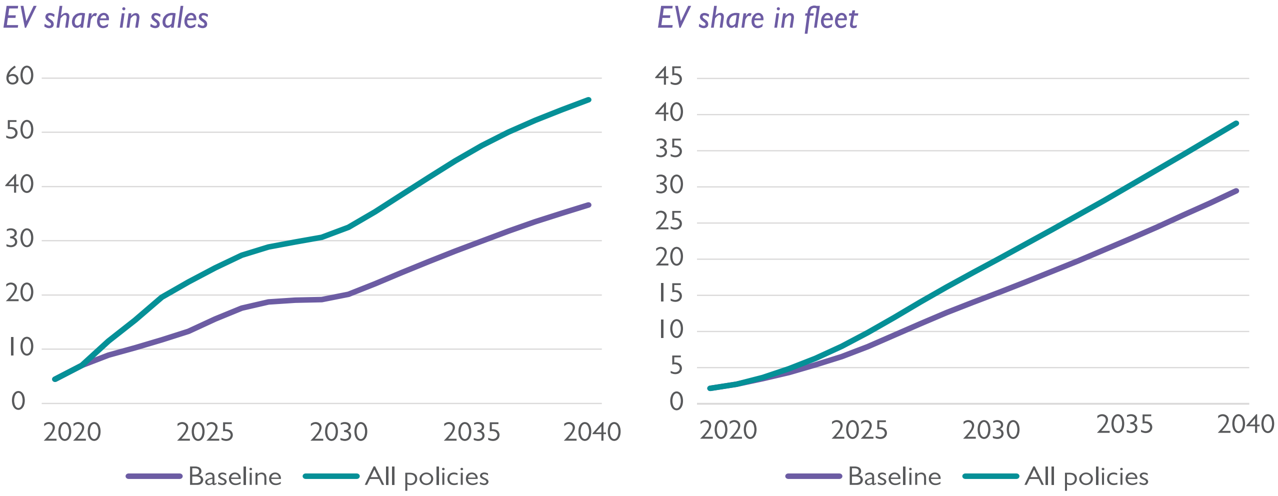
Figure B. Employment impact, % from baseline

Source: World Bank Staff estimates based on E3-Thailand model

To achieve Thailand's ambitious goal of a swift transition to electric vehicles (EVs), a comprehensive set of policies is essential. The adoption of EVs not only aligns with the country's commitment to sustainable development and climate change mitigation, but also presents an opportunity to significantly transform the domestic car industry. While carbon taxes or higher fuel taxes could contribute to supporting the shift to EVs, their overall impact on EV uptake is limited. A more effective approach involves a combination of policies, including substantial public investments in EV infrastructure, electrification of the public fleet, support for the electrification of taxis, and incentives for EV purchases. Figure 3.10 illustrates the potential impact of this range of policies on vehicle sales and fleet composition. Building on an existing trend toward electrification, these policies could result in almost 60 percent of new cars in Thailand being electric by 2040. The early scrapping of conventional vehicles could further accelerate this positive trend.

Transitioning to EVs offers substantial economic and environmental benefits (PER, 2022). Initiating the shift involves introducing a broad range of policies, with climate benefits limited unless there are parallel measures to decarbonize Thailand's power sector. Collaborating with international organizations and private sector partners is also recommended to expedite the transition to EVs (Box 2). This holistic approach will ensure a smoother and more effective integration of EVs into the transportation ecosystem.

Figure 3.10. EV market shares in new vehicle sales and in the vehicle fleet, %



Source: World Bank Staff estimates based on E3-Thailand model

Box 2. The Bangkok E-Bus Program

The Bangkok E-Bus Program marks a milestone as the inaugural authorized climate protection initiative under the bilateral cooperation agreement between Switzerland and Thailand, in alignment with Article 6 of the Paris Agreement. This initiative empowers the private e-bus operator in the Bangkok Metropolitan Area to transition its fleet from diesel to electric vehicles.

Simultaneously, the program lays the groundwork for an extensive city-wide charging infrastructure network. To secure financing, the purchase agreement between Energy Absolute Public Company Limited and the KliK Foundation for GHG emission reductions (International Transferred Mitigation Outcomes, ITMOs) from this program was formalized on June 24, 2022. The reduction in GHG emissions will count towards Switzerland's NDC target rather than Thailand's. However, this climate protection endeavor is poised to enhance significantly air quality in Bangkok and, as a flagship initiative, is expected to spearhead the electrification of Thailand's mobility sector.

Addressing climate change in Thailand could have major fiscal implications, with net costs projected to reach 1 percent of GDP by 2030. The overall impacts of the low-carbon transition on fiscal balances will depend on the exact policy mix. However, without a broader application of carbon pricing, the need for a net increase in public expenditure is expected. Analysis across countries suggests that adaptation costs in Thailand could be at least 1.6 percent of GDP in the 2030s, with the government likely shouldering most of these costs, given the public goods nature of many adaptation measures. The NDC carbon price modeled in the previous section[4] could raise enough revenues to cover this investment cost by 2040 (although not by 2030), but the benefits from using the carbon tax revenues to reduce other tax rates would be lost. Power sector reform to lower emissions would also reduce carbon tax revenues. Revenues from fuel excise duties

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[4] Here excluding road transport, which is covered separately under carbon-related fuel excise duties.

(currently around 1.2 percent of GDP) are expected to rise initially due to duties reflecting the carbon content of fuels, but they will decrease with the transition to electric vehicles, in line with government goals. Excise duties from car sales (currently at 0.8 percent of GDP) would also decline as lower tax rates are applied to low-carbon vehicles. This figure assumes that other sectors, such as transport and forestry, will require relatively small net public contributions.

Table 3.4. Indicative impact of climate-related policies on fiscal balances (% of GDP)

	2025	2030	2035	2040
Adaptation costs	-0.6	-1.6	-1.6	-1.6
Carbon tax revenues	0.4	0.7	1.0	1.6
Fuel excise duties	0.3	0.2	-0.1	-0.7
Vehicle excise duties	-0.2	0.0	0.0	0.0
Other transport measures	-0.4	-0.2	-0.2	-0.1
Forestry sector costs	-0.1	-0.1	-0.1	-0.1
Total	-0.6	-1.0	-1.0	-0.9

Source: World Bank staff estimates, 2024

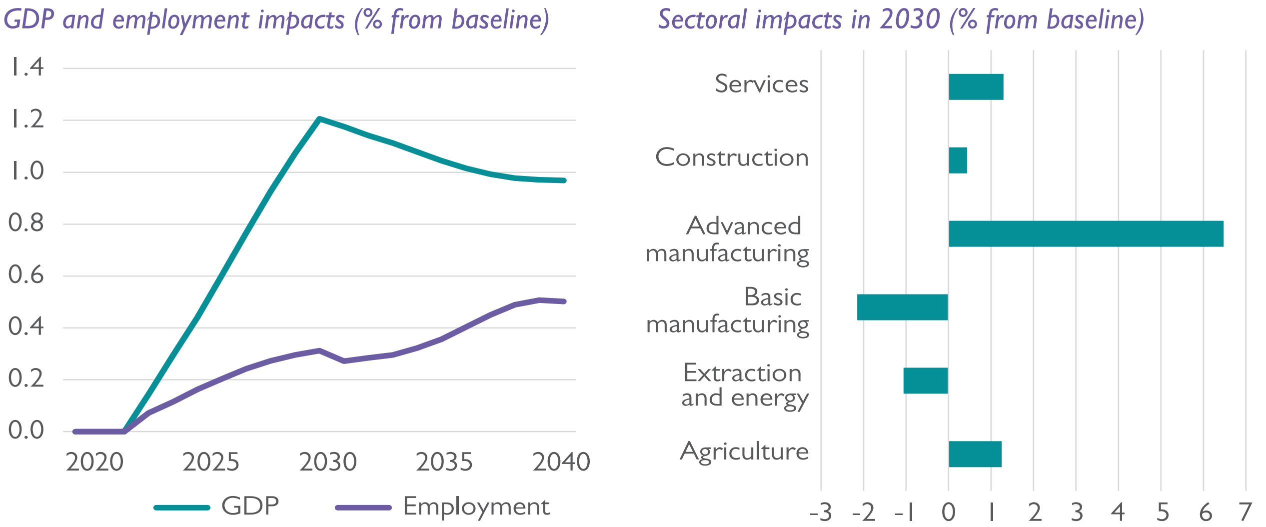
3.6. MOVING TO A MORE CIRCULAR ECONOMY

The modeled scenario entails substantial reform to several key sectors of Thailand's economy. General principles include enhanced product design, extended product lifetimes, increased sharing of goods, and efficient waste management (including increased recycling of steel, plastics, and textiles). However, many of the measures included are specific to the sectors they cover (see Table 3.3). For example, reducing cement use will require new thinking in architecture and construction. A shift to EVs (as described above) requires improvements to infrastructure.

If successful, the transition to a circular economy by 2030 could lead to additional GDP growth and job creation. Meeting the outlined targets might result in an increase in the level of GDP by 1.0 percent and the generation of 160,000 jobs in Thailand by 2030, compared to the baseline scenario (Figure 3.11). These results exclude short-term investment effects and show only the impacts of changing production patterns. The economic benefits arise from improved waste management, with a large share of the total benefits coming from the potential to increase agricultural and food exports (for example due to lower wastage in food production). A focus on transforming waste into new materials across advanced manufacturing and service sectors also increases value added in these sectors and aggregate GDP. Although there is some lost production in domestic extraction, circular economy measures in Thailand generally mean a shift toward local production over imported virgin resources (including motor fuel). Jobs are created in the sectors that do the extra processing. However, the employment gains depend on the availability of skilled workers, requiring a sector-specific assessment.

Sectors with complex manufacturing processes stand to benefit the most from a shift to a circular economy. The model results show that most of the additional production arises in advanced manufacturing sectors. This group includes the repair and waste processing sectors, which will have a much larger role in the circular economy. In contrast, sectors in the basic manufacturing sector, including textiles, chemicals, and building materials, will see a fall in demand because of changes in production methods. Reduced use of raw materials leads to lower output in the extraction sector, while production in other sectors increases slightly, in line with the broader economic results.

Figure 3.11. Potential economic impact of moving to a circular economy



GDP and employment impacts (% from baseline)

Sectoral impacts in 2030 (% from baseline)

Source: World Bank Staff estimates based on E3-Thailand model

4

BALANCING ACT: ASSESSING THAILAND'S ECOLOGICAL THRESHOLDS

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4. BALANCING ACT: ASSESSING THAILAND'S ECOLOGICAL THRESHOLDS

4.1. TIPPING POINTS

This chapter examines the potential impacts of ecological thresholds (tipping points) in Thailand, and the consequences of climate change and ineffective natural capital management. Tipping points are complex, involving multiple variables interacting at different time scales. A tipping point is interpreted as a non-marginal change or a sudden shift after which restoration of an ecosystem to its previous state may no longer be possible. In some ecosystems, tipping points can occur rapidly, such as the classic example of a small pond that becomes eutrophic and no longer able to support some forms of life. In the case of forested ecosystems, tipping points occur over a much longer horizon. To model a tipping point, we focus on climate change and continued deforestation and its impacts on ecosystem service flows.

4.2. AN INTEGRATED ECONOMIC-ENVIRONMENTAL MODEL FOR THAILAND

The chapter uses an IEEM model, which is a data-driven decision-making framework linked to spatial LULC and ESM. It is widely utilized by multilateral institutions and government bodies for cross-sectoral public policy and investment analysis, addressing concerns like climate change, the Sustainable Development Goals, and Green Growth Strategies. IEEM integrates comprehensive environmental data that is available through the United Nations System of Environmental-Economic Accounting (SEEA) and generates key indicators such as GDP, employment, poverty, wealth, sustainability, natural capital stocks, and ecosystem services (ES) supply.

The unique value of IEEM lies in its incorporation of detailed environmental information aligned with the SEEA and the System of National Accounts. IEEM provides policymakers with essential indicators for sustainable economic development, adjusting net national savings for changes in natural capital stocks and environmental damage, rather than prioritizing short-term economic growth at the expense of natural capital assets (Banerjee et al., 2021a).

IEEM's modules capture the dynamics of natural capital-based sectors and, through integration with spatial ESM, estimate impacts on both market and non-market ES. As a single-country recursive dynamic Computable General Equilibrium (CGE) model, IEEM considers all sectors simultaneously, accounting for resource constraints, inter-sectoral linkages, and market interactions. It assesses impacts on material and provisioning ES with market prices, as well as cultural and recreational ES. For non-material or regulating ES without market prices, IEEM is linked with spatial ES modeling, allowing evaluation of impacts on regulating services like erosion mitigation, crop pollination, water regulation, and water purification due to localized LULC changes. The spatial allocation of IEEM-projected land demand is determined through an LULC change model. In its unique application to Thailand, the database underpinning IEEM, the Social Accounting Matrix, is constructed based on the country's latest Supply and Use Tables from 2012, and macro-economic data, government budget data, and balance of payment data from 2019. The Social Accounting Matrix distinguishes 26 production activities, 26 commodities, eight primary production factors, and one household category (see Supplementary Information section 1 for a detailed presentation of IEEM and IEEM+ESM methods).

To assess the impacts and costs of inaction, the Integrated Economic-Environmental Model (IEEM) linked with high-resolution spatial Land Use Land Cover (LULC) change and ecosystem services models (IEEM+ESM; Banerjee et al., 2020a, 2020b) is applied to contrast the "business-as-usual" baseline case with scenarios that represent a portfolio of policies and investments designed to counteract climate change and the associated anthropogenic drivers of degradation.

4.3. LULC CHANGE MODELING

LULC change modeling serves as the crucial link between IEEM and spatial ES modeling. To allocate spatially LULC changes, the analysis employs the CLUE (Conversion of Land Use and its Effects; Verburg et al., 2008a, 1999a) modeling framework. This framework integrates empirically quantified relationships between land use and location factors, incorporating dynamic modeling of competition between land use types. Specifically, the Dynamic CLUE (Dyna-CLUE) model is utilized as a tool well-suited for smaller regional extents (Veldkamp and Verburg, 2004a; Verburg et al., 2021a). The Dyna-CLUE model consists of two modules: a non-spatial demand module, populated with IEEM-derived land demand, and a spatially explicit allocation procedure determining the probability of each LULC class occurrence for each pixel through a suitability analysis. Within the Dyna-CLUE model, the demand module generates annual demands for various land use types based on IEEM. These demands, along with suitability maps calculated for each land-use type, function as inputs for the allocation module. The suitability maps indicate the likelihood of each land use class occurring for each pixel and are developed through binomial logit stepwise regression using explanatory variables (Verburg et al., 2021).

4.4. ESM

The IEEM+ESM workflow employs the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) suite of models (Natural Capital Project, 2023a) to compute spatially explicit changes in ES supply across various scenarios. InVEST models integrate LULC maps with biophysical information to estimate ES. Six ES models were parameterized using both global and national data sources: the sediment delivery ratio model, the carbon storage model, the annual water yield model, the nutrient delivery ratio model, the crop pollination model, and the coastal vulnerability model.

The primary variable influencing changes in the InVEST ES modeling is the scenario-driven LULC projections generated using the Dyna-CLUE model. New LULC maps for each scenario and period are incorporated into each of the five ES models (the coastal vulnerability model does not use LULC as an input). Scenario-driven changes in ES supply for any given year, t, are computed as differences between ES in the scenario for year t and the baseline scenario for that same year. Results are presented as a percentage difference from the baseline for each of Thailand's six regions (North, Northeast, Central, West, East and South).

4.5. MODEL INTEGRATION AND INTERACTION: THE DYNAMIC IEEM+ESM APPROACH

In the basic IEEM+ESM workflow, scenarios are applied in IEEM to assess their impacts on economic indicators. IEEM generates a land demand projection, spatially allocated using the LULC change model. The five ES models (excluding coastal vulnerability) analyze LULC change maps for the initial year, final year, and each scenario. The difference between ES supply in each scenario and the baseline in the final period indicates scenario-based impacts on the ES. When compared with other IEEM+ESM outputs, this approach offers insights into trade-offs between economic, environmental, and social outcomes. ES supply changes have varied economic effects. IEEM addresses impacts for provisioning ES with market values, like food, water, fiber, and minerals. Some cultural ES values related to tourism and recreation are estimated through standard IEEM implementation (Banerjee et al., 2019b). However, the basic workflow lacks economic values for regulating ES without market prices.

The analysis employs the dynamic IEEM+ESM approach, capturing policy impacts on regulating ES by integrating dynamic feedback between natural capital, ES, and the economic system. This enables the estimation of the contribution of regulating ES to economic indicators, in this application, with a focus on changes in soil erosion mitigation ES and crop pollination ES. The demand for land is taken as exogenous and determined by the scenarios. Dyna-CLUE is implemented to allocate spatially land demand, as shown in Figure 4.1. Using LULC maps from LULC modeling, the sediment delivery ratio model (for soil erosion mitigation ES) and the crop pollination model are run in periodic time steps (5-year periods) throughout the analytical period.[5]

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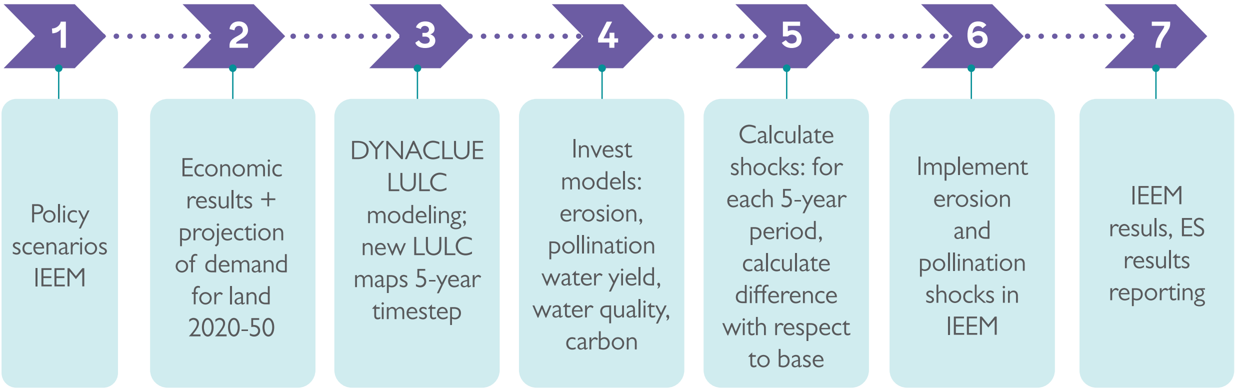
[5] Note that when demand for land is exogenously determined, as is the case in this study where the scenarios define the demand for land, the LULC change model and the ES models are run iteratively to calculate changes in ES and the economic shocks described below. Iteration between all three models (IEEM, the LULC change model and the ES models) is required where there is endogeneity in demand for land (for example, see: Banerjee, Cicowiez, et al. (2020b) and Banerjee, Cicowiez, Malek, et al. (2022)).

Figure 4.1. Overview of the dynamic IEEM+ESM workflow applied to Thailand



Source: Authors' own elaboration.

4.6. SCENARIO OVERVIEW

The model simulations assess the consequences of approaching ecological thresholds (tipping points) and strategies to avert it, utilizing a baseline and two primary scenarios in IEEM+ESM. The baseline scenario projects Thailand's economy until 2050 without significant new policies, investments, or accelerated degradation of natural capital.

The first scenario, DEGRADE, simulates climate change-accelerated ecological degradation, highlighting the costs of policy inaction compared to the baseline scenario. DEGRADE includes sub-scenarios with more rapid and destructive deforestation, increased flooding, catastrophic floods, reduced agricultural productivity, stagnating tourism, sea-level rise, increased erosion, and decreased crop pollination. Some DEGRADE sub-scenarios use Relative Concentration Pathway (RCP) projections, specifically RCP8.5 and RCP4.5 (see Supplementary Information Section 2 for a detailed presentation of the sub-scenario components).

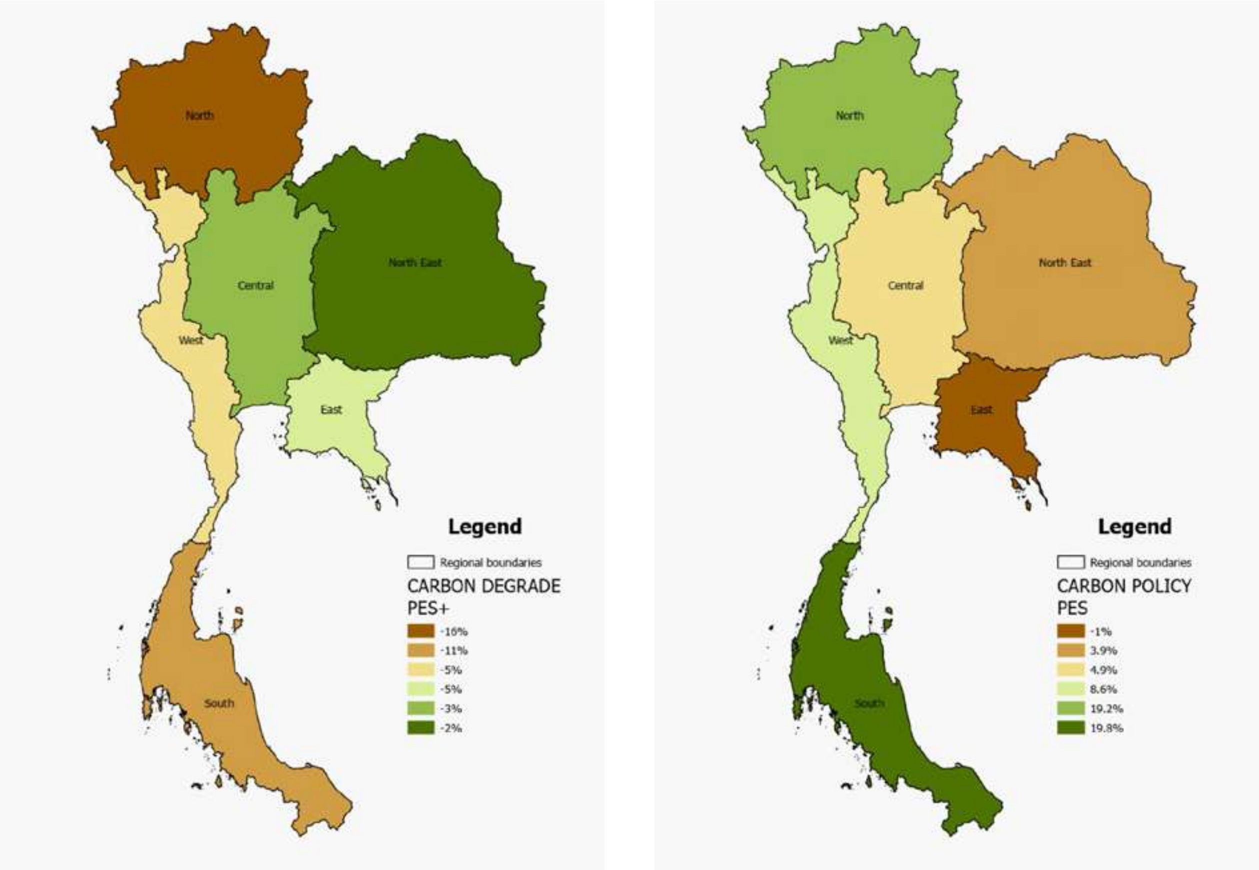
The second scenario, POLICY, represents policies and investments aimed at preventing a tipping point and adapting to climate change. Contrasting the portfolio of policies with the baseline underscores the economic benefits of investing in natural capital enhancement, resilience, and recovery, while revealing potential trade-offs between economic, social, and environmental outcomes. POLICY includes sub-scenarios countering the effects of DEGRADE, as well as initiatives aligning with Thailand's National Strategy, such as the elimination of deforestation by 2037 and afforestation (1,806,400 ha equivalent to 22 percent of current forest cover) and forest restoration (2,558,400 ha equivalent to 31 percent of current forest cover).

4.7. RESULTS

The baseline projection indicates continuous forest loss throughout the analytical period while the DEGRADE scenario depicts an accelerated deforestation rate, potentially eliminating most of Thailand's non-protected forests. The POLICY scenario, conversely, incorporates afforestation measures (1,806,400 ha) and forest restoration (2,558,400 ha), alongside the elimination of deforestation, starting in 2024 and linearly reaching zero new deforestation by 2037. The results that follow focus on the difference between the DEGRADE and POLICY scenarios relative to the baseline in the final year of the analytical period (2050) for each of Thailand's six regions.

The impact on carbon storage ES in the DEGRADE scenario (Figure 4.2, left) reveals that the greatest decreases would occur in the north, south, and west (-16%, -11%, and -5%, respectively). In the POLICY scenario (Figure 4.2, right), carbon storage would notably increase, particularly in the south, north, and west (19.8%, 19.2%, and 8.6%, respectively).

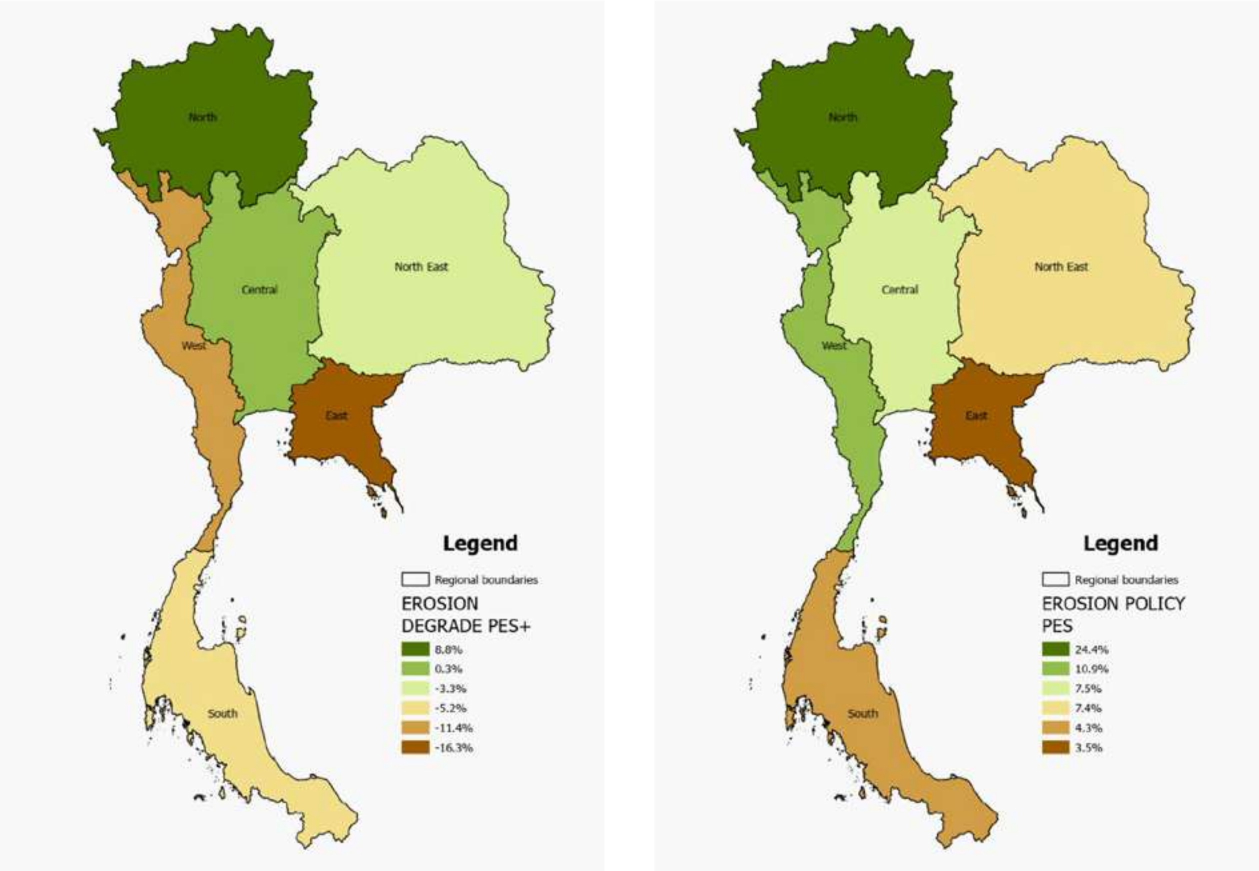
Figure 4.2. DEGRADE PES+ and POLICY PES+ carbon storage climate mitigation ecosystem services in 2050 as a difference from the baseline in percent



Source: IEEM+ESM results. Note: scenario names that terminate in PES+ use the RCP8.5 pathway projection.

For erosion mitigation ES (Figure 4.3, left), a considerable decline is anticipated across most of Thailand as the ecological tipping point approaches, with reductions of 16.3 percent in the east, 11.4 percent in the west, and 5.2 percent in the south. Introducing policy interventions would markedly improve erosion mitigation ES, with increases of 24.4 percent in the north, 10.9 percent in the west, and 7.5 percent in central Thailand (Figure 4.3, right).

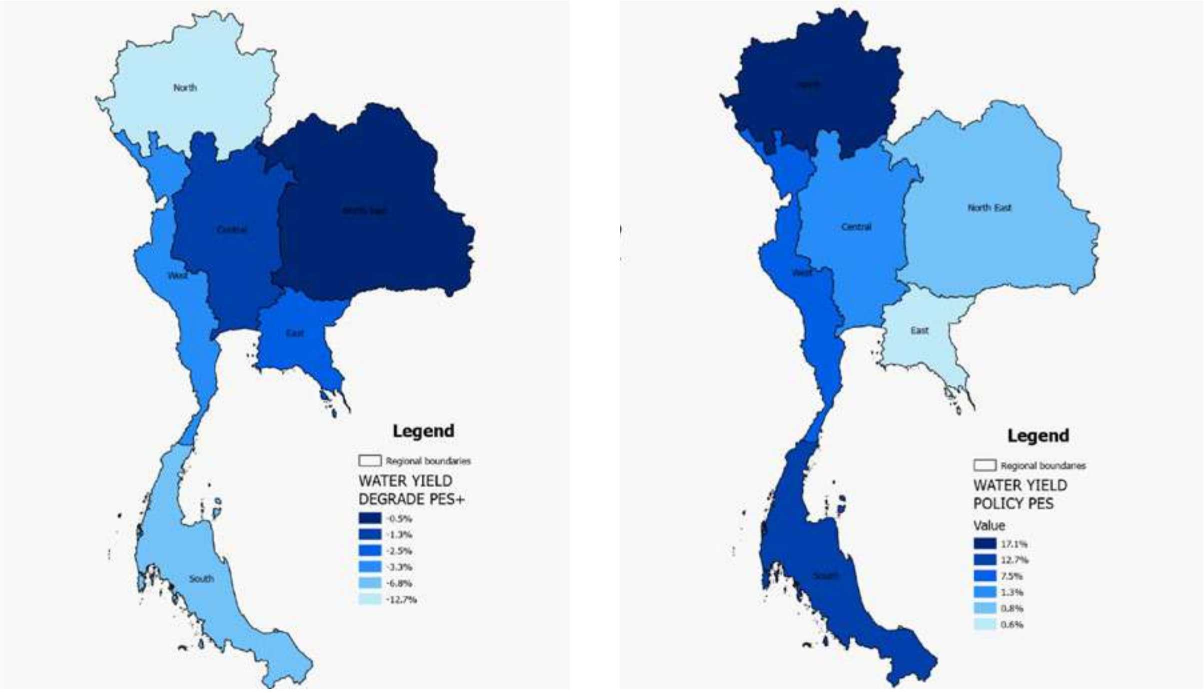
Figure 4.3. DEGRADE PES+ and POLICY PES+ erosion mitigation ecosystem services in 2050 as a difference from the baseline in percent



Source: IEEM+ESM results. Note: scenario names that terminate in PES+ use the RCP8.5 pathway projection.

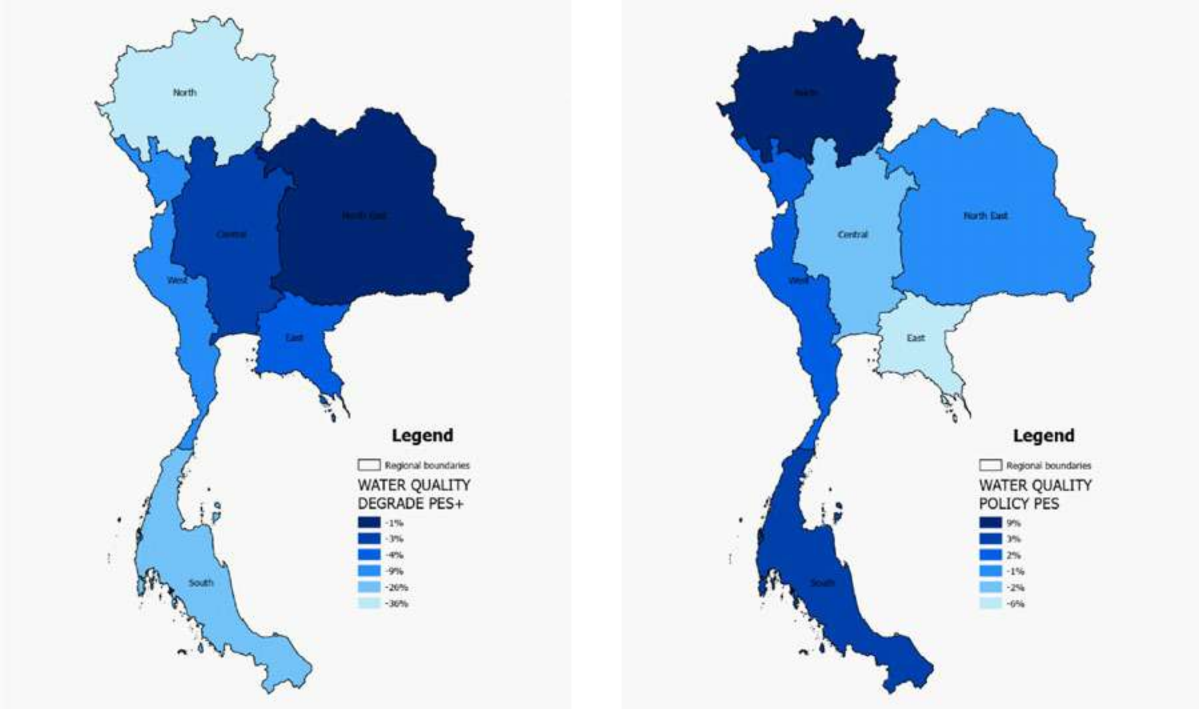
The impacts of approaching a tipping point on water regulation ES Impacts would be negative, particularly for the north, south and west of Thailand (-12.7%, -6.8% and -3.3%, respectively) (Figure 4.4, left). With policy intervention, water regulation ES would be markedly improved, especially in the north, south and west of the country (Figure 4.4, right). With regards to water quality, the DEGRADE scenario would have severe impacts, particularly in the north, south and west of the country (-36%, -26% and -9%, respectively; Figure 4.5, left). With policy intervention, impacts would be strongly mitigated with the greatest effects in the north, south and west (9%, 3% and 2%, respectively; Figure 4.5, right).

Figure 4.4. DEGRADE PES+ and POLICY PES+ water regulation ecosystem services as a difference from the baseline in percent



Source: IEEM+ESM results. Note: scenario names that terminate in PES+ use the RCP8.5 pathway projection.

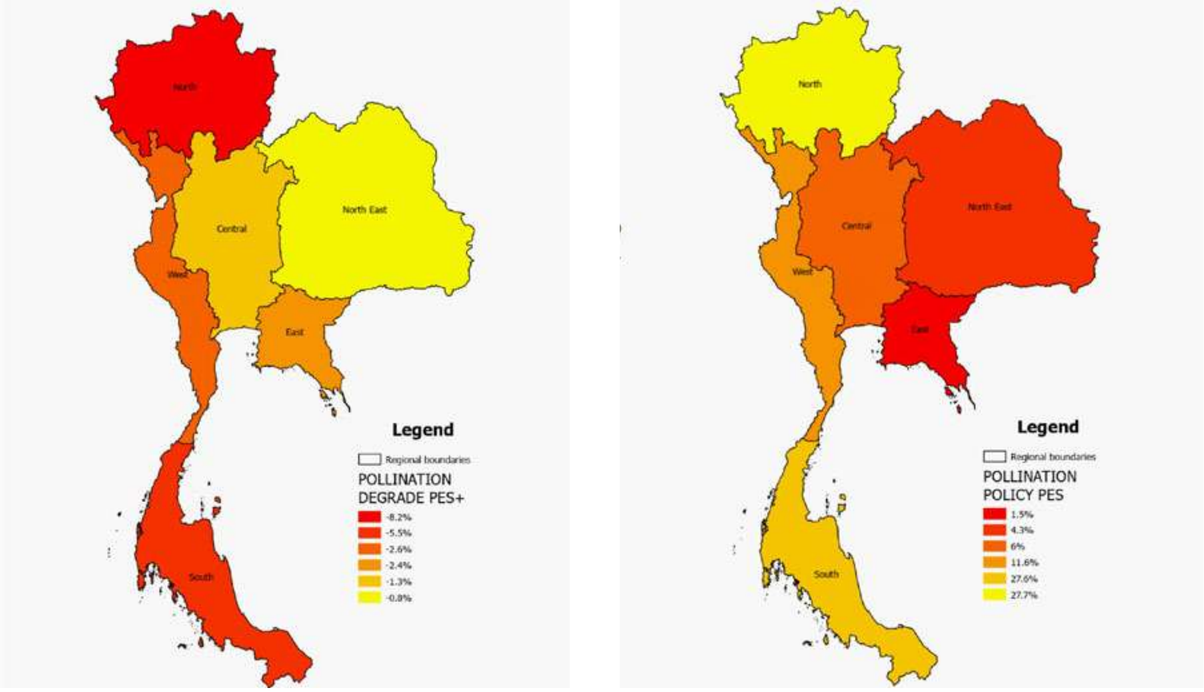
Figure 4.5. DEGRADE PES+ and POLICY PES+ water purification ecosystem services (nutrient retention) as a difference from the baseline in percent



Source: IEEM+ESM results. Note: scenario names that terminate in PES+ use the RCP8.5 pathway projection.

Impacts of approaching an ecological tipping point on crop pollination under DEGRADE would be negative across the country, with the greatest impacts experienced in the north, south and west of Thailand (-8.2%, -5.5% and -2.6%, respectively). The impacts of approaching an ecological tipping point on crop pollination ES are presented (Figure 4.6, left). Again, with policy intervention, these negative impacts would be largely offset with the greatest impacts in the north, south and west of the country (27.7%, 27.6% and 11.6%, respectively; Figure 4.6, right).

Figure 4.6. DEGRADE PES+ and POLICY PES+ crop pollination ecosystem services as a difference from the baseline in percent



Source: IEEM+ESM results. Note: scenario names that terminate in PES+ use the RCP8.5 pathway projection.

Thailand's eastern coastline and gulf region east of Bangkok are the areas exhibiting the highest levels of exposure to coastal vulnerability. Figure 4.7 presents results from the coastal vulnerability modeling. In this application, policy scenarios that affect specific coastal vulnerability variables were not considered. At this stage, Figure 4.7 presents baseline coastal vulnerability.

The contribution of ES to the economy is shown in Table 4.1. In the results that follow, scenario names that terminate in OPT consider the RCP4.5 pathway while those that terminate in PES use the RCP8.5 pathway projection. The RCP8.5 pathway is the highest emissions scenario, and therefore climate change under RCP8.5 is expected to be more severe (scenario name terminating in PES to abbreviate 'pessimistic') compared with RCP4.5 (scenario name terminating in OPT to abbreviate 'optimistic').

Figure 4.7. Baseline coastal vulnerability, index value between 1 (very low exposure) to 5 (very high exposure)

Source: IEEM+ESM results.

Cultural and recreational ES would experience the greatest decline in approaching an ecological tipping point. As would be expected, impacts of scenarios that use RCP4.5 projections versus RCP8.5 projections would be milder, though still negative. Energy ES would be next in terms of negative impacts followed by food provisioning ES. Crop pollination and erosion mitigation ES would also decline.

ES losses as an ecological tipping point approached would result in an overall net loss of $177.6 billion in ES values (DEGRADE_PES+). Policy intervention would mitigate some of this loss. Regulating ES would make positive contributions, but some losses would still be incurred through the loss of provisioning and cultural and recreational ES, resulting in a net impact of $39 billion in ES losses with policy implementation (POLICY_PES+).

Table 4.1. Contribution of Ecosystem Services (ES) to the economy as a cumulative difference from the baseline in 2050 in USD million

ES Section	ES Class	Scenario			
		DEGRADE_OPT	DEGRADE_PES+	POLICY_OPT	POLICY_PES+
Provision ecosystem services					
	Food (plant-based)	-6,834	-79,786	-7,074	-22,477
	Meat (excluding fish)	-1,335	-7,672	-1,895	-3,159
	Fish	-1,845	-2,996	-4,786	-1,138
	Timber and non-timber	499	3,224	-4,786	-3,631
	Abiotic subsurface minerals	-15,257	-10,361	-11,402	-9,525
	Abiotic subsuface non-mineral energy	-1,641	-1,454	541	814
Cultural and recreational ecosystem services					
	Culture, recreation and tourism	-26,256	-61,156	-5,103	-17,930

ES Section	ES Class	Scenario			
		DEGRADE_OPT	DEGRADE_PES+	POLICY_OPT	POLICY_PES+
Regulating ecosystem services					
	Crop pollination	-7,508		17,749	
	Erosion mitigation	-9,871		285	

Source: IEEM+ESM results. Note: scenario names that terminate in OPT consider the RCP4.5 pathway while those that terminate in PES use the RCP8.5 pathway projection.

The POLICY scenario would result in an increase in CO_2 storage equivalent to 2,103 million tons compared to the baseline. The elimination of deforestation would result in a net 189-million-ton increase in CO_2 storage. Afforestation and forest restoration activities that are components of the POLICY scenario, would result in the storage of an additional 1,913 million tons of CO_2.

The cumulative GDP impact from loss of ES could be a negative $553.7 billion by 2050 (Table 4.2). Policy intervention would reduce these losses significantly, though the impact would still be negative ($174.9 billion). With the elimination of deforestation as well as afforestation and forest restoration activities, the policy interventions to avert an ecological tipping point would enhance cumulative wealth by $54 billion. Detailed results for each sub-scenario are presented in Supplementary Information Section 3, including macro-economic results expressed in percentage change.

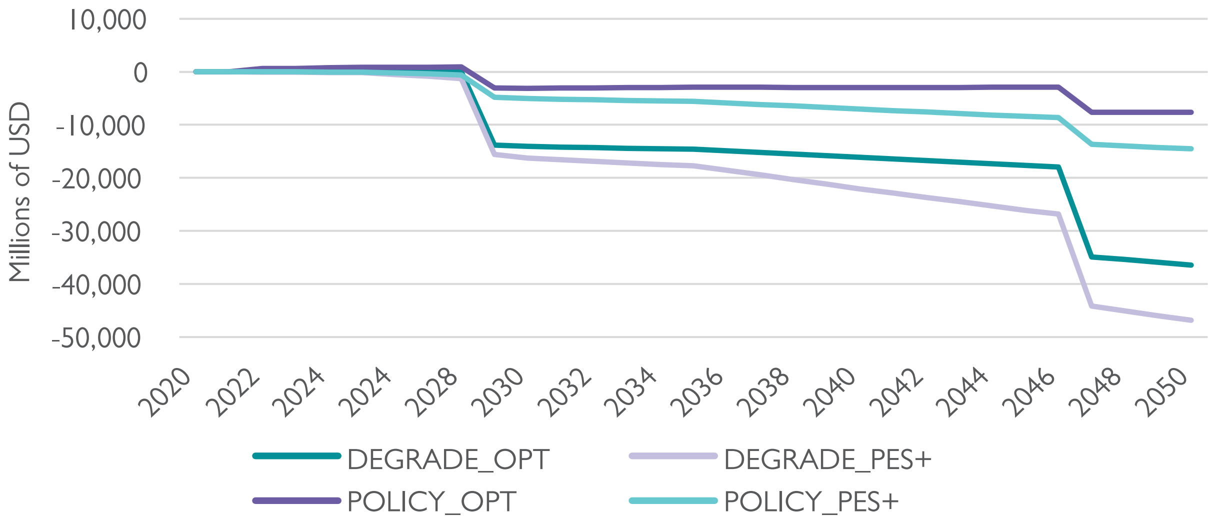
Table 4.2. Impacts on macro-economic indicators as a difference from the baseline in 2050 or cumulative impact as indicated in USD million

	DEGRADE_OPT	DEGRADE_PES+	POLICY_OPT	POLICY_PES+
GDP	-36,442	-46,878	-7,658	-14,548
Cumulative GDP	-423,101	-553,708	-80,056	-174,902
Wealth	-6,564	-6,888	-1,649	2,669
Cumulative wealth	-75,420	-80,530	-18,238	54,490
Private consumption	-27,392	-39,652	-5,515	-11,143
Private investment	-11,999	-11,287	-2,674	-4,217
Exports	-34,314	-37,279	-25,383	-24,324
Imports	-32,551	-35,136	-3,721	-5,129

Source: IEEM+ESM results. Note: scenario names that terminate in OPT consider the RCP4.5 pathway while those that terminate in PES use the RCP8.5 pathway projection.

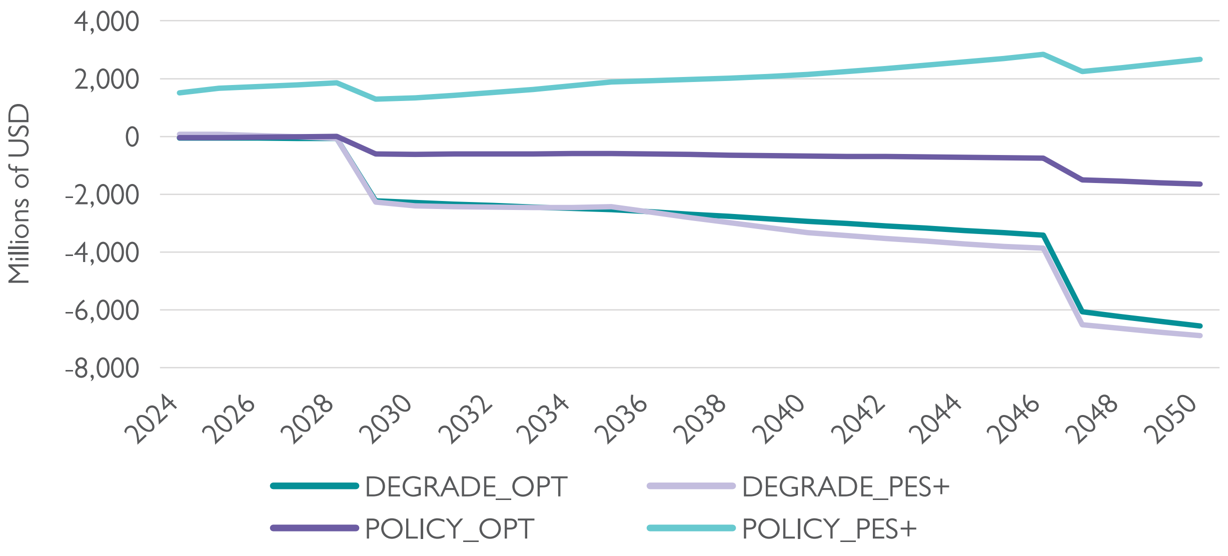
Figure 4.8 presents the GDP trajectory of each scenario while Figure 4.9 presents the wealth trajectory, both as a difference from the baseline. The "steps" visually evident in both these figures are the result of the impacts of catastrophic floods occurring in the years 2029 and 2047. These specific years were chosen through a random number draw.

Figure 4.8. GDP trajectory as a difference from the baseline in USD million



Source: IEEM+ESM results. Note: scenario names that terminate in OPT consider the RCP4.5 pathway while those that terminate in PES use the RCP8.5 pathway projection.

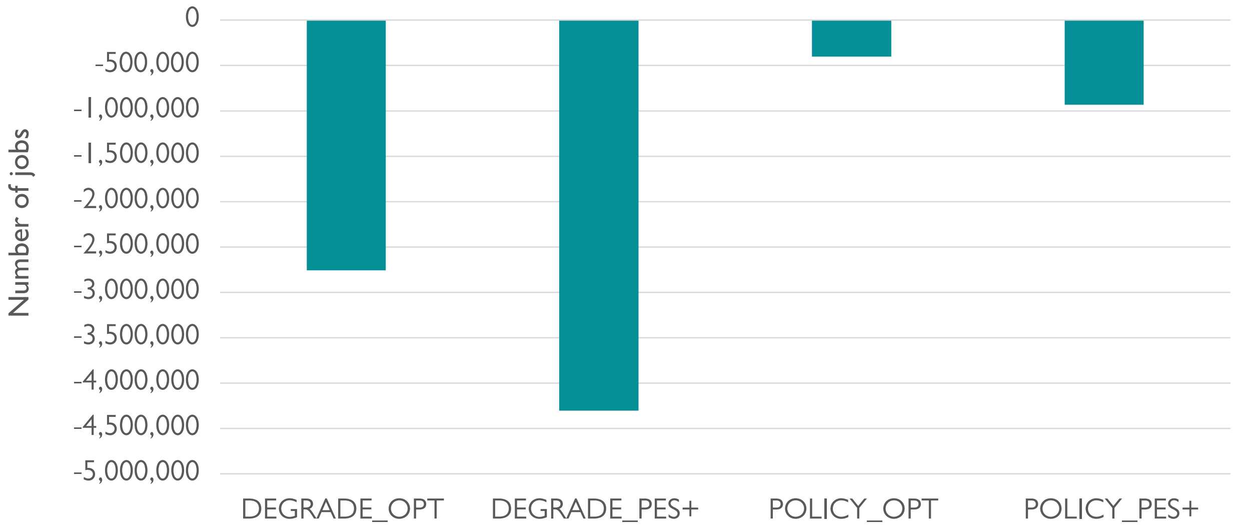
Figure 4.9. Wealth trajectory as a difference from the baseline in USD million



Source: IEEM+ESM results. Note: scenario names that terminate in OPT consider the RCP4.5 pathway while those that terminate in PES use the RCP8.5 pathway projection.

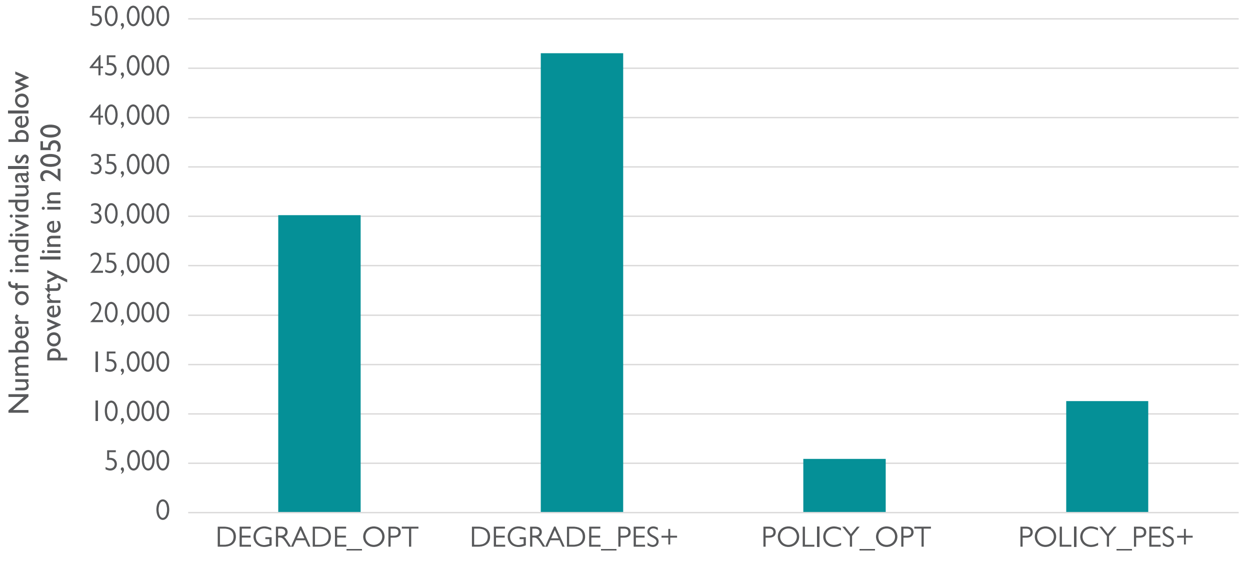
Employment would fall cumulatively by more than 4.3 million jobs (Figure 4.10). Policy intervention would mitigate much of this impact, though the result would still be a loss of 931,000 jobs. The DEGRADE_PES+ scenario would result in 46,510 more poor while policy intervention would reduce the impact but still result in 11,283 more poor (Figure 4.11).

Figure 4.10. Scenario impacts on employment as a difference from the baseline in 2050



Source: IEEM+ESM results. Note: scenario names that terminate in OPT consider the RCP4.5 pathway while those that terminate in PES use the RCP8.5 pathway projection.

Figure 4.11. Change in number of individuals in poverty as a difference from the baseline in 2050



Source: IEEM+ESM results. Note: scenario names that terminate in OPT consider the RCP4.5 pathway while those that terminate in PES use the RCP8.5 pathway projection.

Examining the household welfare impacts of the scenarios in a benefit-cost framework, the POLICY_OPT scenario would result in a negative return of $32.3 million with a 2.5 percent opportunity cost of capital and a negative $8.4 million return with a 10 percent opportunity cost of capital. With a discount rate of 2.5 percent and 10 percent, the POLICY_PES+ scenario would result in a return of negative $78.4 million and negative $23,9 million, respectively.

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5

OVERALL CONCLUSION AND RECOMMENDATIONS

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5. OVERALL CONCLUSION AND RECOMMENDATIONS

5.1. A WAY FORWARD

Thailand launched its Bio-Circular-Green (BCG) economic model in 2021 with the goal of combining the country's biological and cultural diversity with technological innovation to ensure sustainable future growth. The BCG model focuses on four sectors: food and agriculture; human health; bio-based material and energy; and tourism and the creative economy.

As one of the world's most vulnerable countries to climate change, Thailand faces severe sustainability challenges due to rising sea levels, extreme weather events, and changing precipitation patterns. Addressing issues such as deforestation, coastal degradation, and implementing climate adaptation measures is paramount, requiring a combination of policies and strategies that cut across all levels of society — government, business, political, and social — to promote resiliency to climate impacts and economic sustainability.

Thailand also faces a challenge in reducing its own GHG emissions. To date, Thailand's CO_2 emissions in the energy sector have grown almost proportionately with GDP (although other emissions have grown more slowly). While the use of renewable electricity generation may slow CO_2 emission growth, the general trend in emissions after the COVID pandemic is not yet clear. The pandemic means that Thailand may meet its current NDC target of slower absolute emission growth relatively easily, but it will increasingly come under pressure to reduce its level of GHG emissions.

This report focuses on BCG+, which is a combination of the previous BCG vision and the current climate reality. The move towards a BCG and climate-resilient economy is a critical shift for Thailand, offering protection against environmental and economic risks that threaten growth. A BCG+ economy could mitigate these exposures by reducing reliance on global commodity prices and enhancing economic resilience.

The uneven distribution of climate impacts across the country highlights the need for targeted interventions to address specific vulnerabilities. Thailand's population is predominantly concentrated in urban areas, with rapid urbanization increasing the vulnerability of densely populated concentrations to climate-related risks, particularly floods. Lower-income households, often residing in hazard-prone areas, face greater challenges due to limited access to essential services. The country's vital agricultural sector is also significantly threatened by altered rainfall patterns and temperature extremes, jeopardizing crop production.

5.2. MULTI-SECTOR PARTICIPATION

Achieving the transition to a BCG+ economy requires contributions from all sectors, with a focus on sector-specific characteristics. While some sectors such as forestry stand out as being critical to a BCG+ economy, the transition will need contributions from all sectors. For example, the challenge of reducing GHG emissions will likely require a restructuring of the power sector, electrification of vehicle transport, and changes to industrial production processes. The circular economy modeling in this report identified multiple policies that were specific to the sectors covered. Electrification of transport likewise requires a range of policies specific to the sector. When considering climate adaptation, location is likely to be a critical factor but several sectors (e.g. transport, tourism, fishing) require potentially vulnerable coastal locations.

Macro-level policies, including carbon taxes, are important but must consider technological nuances for effectiveness. The carbon taxes tested in this report were sufficient to prevent emissions from growing but, in isolation, could not drive major reductions in emissions. Promoting circular production methods poses additional challenges because of the multiple inputs and outputs in the business model. Coordination between the public and private sectors will be imperative to realizing the BCG+ vision. The public sector must initiate change, finding financing solutions for actions like climate adaptation. Simultaneously, private companies bear responsibility for improving efficiency, fostering innovation, and aligning product designs with bio-circular goals. For carbon taxes to be effective, power sector reforms are essential in Thailand to ensure a reliable and equitable transition to low-carbon energy sources. These reforms can help align pricing signals with carbon reduction goals, driving investments in cleaner technologies and enhancing overall efficiency within the sector.

If these policy challenges can be met, the transition could offer macro-level opportunities, showcasing potential benefits like increased economic welfare, higher incomes, and enhanced employment levels. These positive impacts could offset many of the damages of climate change, especially if there is a strong role for flood prevention and climate adaptation measures. Technological advancements and undiscovered productivity avenues underpin these opportunities, positioning the Bio-Circular Green economy as a driver for economic development. As a country that imports many of its material inputs, Thailand could boost domestic production. Crucially, the shift to a BCG+ growth model could safeguard Thailand from future climate and economic risks while preserving natural capital for sustainable growth.

5.3. ECOLOGICAL THRESHOLDS

Thailand must act urgently to prevent ecological tipping points regarding deforestation and flooding that threaten billions of dollars in economic losses. The report analyzes the severe impacts of Thailand approaching an ecological tipping point and proposes preventive strategies. It compares two scenarios: DEGRADE, leading to increased deforestation and flooding, and POLICY, involving interventions to mitigate these effects. Thailand's forest cover has declined by 12% since 2000, risking further reductions if deforestation continues. Eliminating deforestation and promoting reforestation are highlighted as effective and low-cost measures to enhance ecosystem services (ES) like water regulation, crucial for flood management. Without action, Thailand could face $553 billion in GDP losses by 2050. Policy measures could reduce these losses by 68 percent and increase wealth. However, these policies alone are insufficient to counteract fully environmental degradation. The report underscores the need for detailed climate adaptation and mitigation plans, emphasizing that preserving natural capital is vital for resilience against climate change, especially in mitigating flood impacts. Comprehensive economic frameworks that include the value of ES are essential for sustainable policy and investment decisions.

Addressing the multifaceted consequences of economic growth constraints, climate vulnerability, and environmental degradation requires a holistic and integrated approach. By integrating measures on climate resilience, sustainable resource management, and inclusivity in its development strategy, Thailand can work towards achieving its vision of a BCG+ economy.

5.4. ACTION PRIORITIES

While all actions discussed in this report are valuable, some are more urgent than others. Table 5.1 provides a guide for defining priority actions based on three criteria: urgency, co-benefits, and feasibility. Certain actions are particularly urgent because they generate or facilitate subsequent opportunities and benefits, such as governance enhancements that enable larger adaptation investments. The report classifies the urgency of each action into short-term priorities (by 2030), medium-term priorities (by 2040), and long-term priorities (beyond 2040-50). Some measures are expected to advance both climate and development goals by improving economic opportunities regardless of climate impacts. These include measures that enhance economic and fiscal management, governance, and implementation capacity, as well as those that create new jobs and income opportunities.

Table 5.1. Prioritization Approach for Policy Actions

Urgency (When to act)	Co-benefits (Development co-benefits from climate actions)	Feasibility (Financing needs and enabling conditions)
Short-term (S)	3	Highly Likely (HL)
Medium-term (M)	2	Likely (L)
Long-term (L)	1	Less Likely (LL)

5.4.1. Adaptation

Adaptation Strategies for Climate Resilience

To mitigate the impacts of river floods on communities and infrastructure, it is essential to implement early warning systems and disaster preparedness measures in flood-prone areas. Improving access to essential services like healthcare, education, and early warning systems for lower-income households will enhance their resilience to climate-related impacts. Infrastructure investments should consider increased climate risks, while land use policies must be developed and enforced to prevent urban expansion in hazard-prone areas and protect natural buffers such as forests and wetlands. Sustainable land use practices and reforestation efforts should be promoted to reduce the risk of landslides and erosion in mountainous regions. Additionally, green infrastructure and sustainable urban planning should be implemented to minimize the impact of extreme weather events and flooding in urban areas.

The roles of the public and private sectors in addressing river floods and other climate challenges are distinct but complementary. The public sector is crucial in establishing early warning systems, developing disaster preparedness measures, and creating policies that enhance resilience, especially for lower-income households. Government actions such as enforcing land use policies to prevent urban sprawl in hazard-prone areas and protecting natural buffers are vital for mitigating climate change impacts. Public investment in infrastructure must consider increased climate risks to better protect communities from extreme weather events.

The private sector can integrate sustainable practices and innovative solutions into its operations. Businesses can invest in green infrastructure and sustainable urban planning, which are essential for minimizing the impact of extreme weather events and flooding in urban areas. The private sector's role in financing and implementing these measures, in collaboration with public sector policies and support, is critical for achieving effective and comprehensive adaptation strategies. Collaboration between the public and private sectors, supported by public-private partnerships, is key to building resilient communities and reducing vulnerabilities to climate-related impacts.

The modeling conducted in this study provides valuable insights that inform key policy recommendations for Thailand's climate change adaptation efforts. These recommendations are crucial for enhancing resilience and mitigating the impacts of climate-related events. Table 5.2 elaborates on the key recommendations.

Table 5.2. Priority Adaptation Actions

Action	Description	Urgency	Co-benefits	Feasibility
Implement flood management strategies	Given the significant projected impact of floods, Thailand must prioritize comprehensive flood management strategies to reduce the vulnerability of communities and infrastructure. Key measures include investing in flood control infrastructure like levees and flood barriers, implementing nature-based solutions such as wetland restoration and floodplain zoning, and strategically locating new infrastructure away from flood-prone areas. Enhancing resilience through improved drainage systems and promoting green infrastructure can further mitigate the adverse impacts of floods. (Ministry of Natural Resources and Environment, Ministry of Interior, Urban Local Bodies and Communities)	S	3	L

Action	Description	Urgency	Co-benefits	Feasibility
Develop early warning systems and enforce building regulations	Early warning systems are vital for preparedness and reducing the risk of loss during extreme weather events. Thailand should invest in advanced technologies and community engagement for these systems. Enforcing building regulations to ensure structures can withstand and are elevated above flood levels is essential. Strategic planning and zoning in flood-prone areas, guided by risk assessments, can minimize exposure, and promote sustainable development. (Ministry of Natural Resources and Environment, Ministry of Interior, Ministry of Agriculture, Local Government Units and Community Organizations)	S	3	L
Enhance coastal resilience	With the increasing threat of sea-level rise and coastal erosion, Thailand should enhance coastal resilience. This includes implementing nature-based solutions like mangrove restoration and beach nourishment and investing in hard infrastructure like seawalls and breakwaters. Developing coastal zone management plans that integrate climate considerations and involve local communities is crucial for sustainable coastal adaptation. (Department of Marine and Coastal Resources, Department of National Parks, Wildlife and Plant Conservation. Local Community Groups)	M	2	HL
Promote climate-smart agriculture	Climate change poses significant risks to Thailand's agriculture, crucial for food security and livelihoods. To build resilience, Thailand should promote climate-smart practices like crop diversification, water-efficient irrigation, and soil conservation. Providing farmers with access to climate information and extension services will help them to adapt and minimize crop losses. (Ministry of Agriculture and Cooperatives, Ministry of Natural Resources and Environment, Local Government Units and Community Organizations, Research Institutions and Academia)	M	1	L
Strengthen urban resilience	As urbanization accelerates, cities in Thailand face increased climate-related risks like heatwaves, urban flooding, and infrastructure damage. Investing in green infrastructure, such as parks and green roofs, can mitigate the urban heat island effect and reduce flood risk.	L	2	LL

Action	Description	Urgency	Co-benefits	Feasibility
	Integrating climate considerations into urban planning and design, including climate-responsive building codes and sustainable transport systems, will enhance urban resilience and promote sustainable development. (Ministry of Interior, Ministry of Natural Resources and Environment, Ministry of Digital Economy and Society, Local Government Units and City Planning Authorities, Private Sector and Industry)			
Enhance community-based adaptation	Recognizing the importance of local knowledge and community participation, Thailand should prioritize community-based adaptation approaches. Empowering local communities to implement tailored adaptation measures will enhance grassroots resilience. Supporting community-led initiatives, such as climate-resilient agriculture and disaster risk reduction activities, can build social cohesion and strengthen adaptive capacity. (Ministry of Agriculture and Cooperatives, Ministry of Natural Resources and Environment, Local Government Units and Community Organizations)	L	2	L
Invest in climate-resilient infrastructure	Climate-proofing infrastructure investments is essential for reducing vulnerability to climate change impacts. Thailand should integrate climate considerations into infrastructure planning, design, and maintenance across sectors like transportation, energy, and water management. This includes incorporating climate risk assessments, designing infrastructure to withstand extreme weather, and ensuring robust maintenance and monitoring systems. (Ministry of Transport, Ministry of Energy, Ministry of Interior. Local Government Units and Municipal Authorities, Private Sector and Industry)	M	2	L

Overall, the integration of these recommendations into Thailand's climate adaptation strategies is paramount for fostering a resilient economy, enhancing quality of life, and safeguarding the planet for future generations. Investing in adaptation measures protects vulnerable communities and infrastructure from the impacts of climate change and strengthens the economy by reducing disaster-related losses and enhancing productivity in sectors such as agriculture and tourism. Moreover, building resilience to climate change fosters social cohesion and inclusivity, ensuring that no one is left behind in the face of environmental challenges.

5.4.2. Mitigation

Thailand faces significant challenges in mitigating its carbon footprint and achieving carbon neutrality by 2050, grappling with rapid urbanization, industrial growth, and reliance on fossil fuels. To succeed, Thailand must enact comprehensive policies, invest in renewable energy infrastructure, and promote clean technologies. Table 5.3 elaborates on the key mitigation recommendations.

In Thailand's quest for carbon neutrality by 2050, the roles of the public and private sectors in mitigation are distinct yet interconnected. The public sector is crucial in crafting and enforcing policies, such as carbon pricing and renewable energy incentives, that establish a framework for reducing emissions. Government investment in renewable infrastructure and public awareness campaigns is essential to create a supportive environment for sustainable development. Meanwhile, the private sector must implement these policies through innovation and investment in clean technologies. Businesses drive the transition to renewable energy and enhance energy efficiency across industries. The adoption of electric vehicles and other low-carbon technologies by private enterprises can significantly reduce the carbon footprint of transportation and other sectors. Effective collaboration between government and industry is essential, with public policies and incentives aligning with private sector initiatives to ensure a unified approach to carbon mitigation.

Table 5.3. Priority Mitigation Actions

Action	Description	Urgency	Co-benefits	Feasibility
Implement carbon pricing mechanisms	Introducing carbon pricing mechanisms, such as a carbon tax or emissions trading scheme, in Thailand can incentivize businesses to reduce carbon emissions. These mechanisms encourage cleaner technologies and practices, leading to reduced emissions. Revenue from carbon pricing can be reinvested in climate mitigation and adaptation efforts, enhancing Thailand's resilience to climate change. (Ministry of Finance, Ministry of Environment and Natural Resources, Ministry of Industry, Ministry of Energy, Ministry of Agriculture and Cooperatives, Private Sector and Industry)	S	2	HL
Power sector reforms	The Government of Thailand should prioritize power sector reforms to enhance the effectiveness of carbon taxes. By aligning energy pricing with carbon reduction goals, these reforms would encourage investment in cleaner technologies and support a smoother transition to a low-carbon economy. (Ministry of Energy, Electricity Generating Authority of Thailand, Ministry of Finance, Energy Regulatory	S	3	L

Action	Description	Urgency	Co-benefits	Feasibility
	Commission, Department of Alternative Energy, Development and Efficiency, Private Sector and Industry, International Organizations and Development Partners)			
Utilize carbon tax revenues to support other climate policy	The revenue generated from carbon taxes could be channeled into a dedicated climate fund, supporting other critical climate policies and initiatives, further accelerating the country's transition to a low-carbon climate resilient economy. (Ministry of Finance, Ministry of Energy, Office of the National Economic and Social Development Council. Climate Change Department, Ministry of Environment and Natural Resources, Energy Regulatory Commission)	S	3	HL
Collaborate for electric vehicle transition	Collaborating with international organizations and private sector partners can accelerate Thailand’s transition to electric vehicles (EVs). By sharing knowledge, expertise, and resources, Thailand can address barriers to EV adoption, such as high upfront costs and limited charging infrastructure. These partnerships can also foster domestic EV manufacturing capabilities, creating new opportunities for economic growth and innovation. (Automobile Manufacturers, Charging Infrastructure Providers, Energy Companies, Ministry of Energy, Ministry of Transport, Thailand Board of Investment)	M	2	L
Implement a comprehensive EV policy package	Thailand can promote widespread EV adoption through a comprehensive policy package. This could include incentives for EV purchases, subsidies for charging infrastructure, and tax breaks for manufacturers. By addressing both supply and demand-side barriers, Thailand can create a supportive environment for EV uptake, reduce GHG emissions from transportation, and improve urban air quality. (Ministry of Energy, Ministry of Transport, Department of Land Transport Electricity Generating Authority of Thailand, Thailand Board of Investment, Ministry of Finance, National Science and Technology Development Agency. Office of the National Economic and Social Development Council)	M	2	L

Action	Description	Urgency	Co-benefits	Feasibility
Implement afforestation and forest restoration measures	Thailand can mitigate climate change and protect ecosystems by implementing afforestation and forest restoration measures. Restoring degraded forests and expanding green cover will sequester carbon dioxide, enhance biodiversity, and provide economic benefits such as job creation in forestry and opportunities for ecotourism. These measures are essential for Thailand's long-term climate resilience and sustainability. (Ministry of Natural Resources and Environment, Department of National Parks, Wildlife and Plant Conservation, Royal Forest Department, Department of Land Development, Ministry of Agriculture and Cooperatives, Office of the National Economic and Social Development Council, Local Government Units and Municipal Authorities, Private Sector and Non-Governmental Organizations)	L	2	L
Enhancing Energy Efficiency	Improving energy efficiency in Thailand is essential for reducing consumption and greenhouse gas emissions. Measures include adopting strict efficiency standards, promoting energy-efficient building designs, and using smart grid technologies. Incentives for energy audits and savings technologies, along with public awareness campaigns and training, will support a transition to a greener economy and lower overall energy demand. (Ministry of Energy, Department of Alternative Energy Development and Efficiency, Energy Regulatory Commission Ministry of Interior, Office of the National Economic and Social Development Council, Thai Green Building Institute, Local Government Units and Municipal Authorities, Private Sector and Industry Associations)	M	2	L

By adopting these tailored policies and measures, Thailand can effectively mitigate climate change, promote sustainable development, and build a more resilient and prosperous future for its citizens. Collaboration, innovation, and strong policy frameworks will be key to achieving Thailand's climate goals and ensuring a livable planet for future generations.

5.4.3. Circular economy

Adopting a circular economy is crucial for Thailand, especially to address the plastic waste crisis affecting the Chao Phraya River. This development model provides a comprehensive solution by reducing plastic use, enhancing recycling and reuse, and minimizing waste. Table 5.4 details key recommendations for transitioning to a circular economy.

To tackle plastic pollution and move towards a circular economy, the public and private sectors must collaborate. The public sector should establish regulatory frameworks, implement policies like extended producer responsibility (EPR), and invest in waste management infrastructure. It should also promote eco-design standards and run awareness campaigns to encourage sustainable consumer behavior. The private sector's role involves applying these policies through innovation, redesigning products to reduce plastic use, and investing in advanced recycling technologies. Efficient value chains for material reuse and repurposing are essential. By aligning public policy with private sector practices, Thailand can effectively address plastic waste and advance towards a sustainable circular economy.

Table 5.4. Priority Circular Economy Actions

Action	Description	Urgency	Co-benefits	Feasibility
Policy Framework for Circular Economy	The Thai government should create a comprehensive policy framework for a circular economy, including regulations, incentives, and guidelines to promote sustainable design, resource efficiency, and waste reduction. Setting clear targets and timelines will guide and hold stakeholders accountable across sectors. (Ministry of Natural Resources and Environment, Department of Environmental Quality Promotion, Ministry of Industry, Office of the National Economic and Social Development Council, Department of Industrial Works, Thailand Board of Investment, Local Government Units and Municipal Authorities)	M	2	HL
Support Innovation and Technology	Thailand should leverage innovation and technology to advance the circular economy. Investing in research and development will help scale up technologies for recycling, remanufacturing, and resource recovery. Embracing digital technologies and data analytics can optimize resource use and support circular business models. By fostering a culture of innovation, Thailand can lead in sustainable resource management and circular solutions. (Ministry of Science and Technology, National	M	3	L

Action	Description	Urgency	Co-benefits	Feasibility
	Science and Technology Development Agency, Ministry of Industry, Department of Industrial Works Office of the National Economic and Social Development Council, Thailand Board of Investment, Private Sector and Industry Associations, Universities and Research Institutions)			
Circular Procurement	Promoting circular procurement practices is essential for driving demand for sustainable products and services in Thailand. The government can lead by incorporating circularity criteria into public procurement. Clear guidelines for evaluating product and service circularity will encourage businesses to adopt circular practices. By boosting market demand for circular products, Thailand can foster innovation, investment, and progress toward sustainability goals. (Ministry of Finance, Office of the Public Procurement, Ministry of Commerce, Department of Internal Trade, Ministry of Industry, Thailand Board of Investment, Office of the National Economic and Social Development Council, Private Sector and Industry Associations, Environmental Non-Governmental Organizations)	M	2	HL
Product Design Improvements	Thailand can encourage businesses to focus on eco-design principles, such as durability, repairability, and recyclability, in product development. Offering incentives and support for sustainable design will help reduce waste and improve resource efficiency. Designing products for easy disassembly and component reuse can extend their lifespan, minimize new resource extraction, and reduce environmental impact. (Ministry of Industry, Department of Industrial Works, National Science and Technology Development Agency, Thailand Board of Investment, Office of the National Economic and Social Development Council, Private Sector and Industry Associations, Environmental Non-Governmental Organizations, Universities and Research Institutions)	M	2	L

Action	Description	Urgency	Co-benefits	Feasibility
Enhanced Material Recycling	Thailand should develop and invest in robust recycling infrastructure and technologies to facilitate efficient collection, sorting, and processing of recyclable materials. By establishing comprehensive recycling programs and promoting consumer awareness and participation, Thailand can increase recycling rates and divert more waste from landfills. Partnering with the private sector and incentivizing investment in recycling facilities can accelerate the transition to a circular economy. (Ministry of Natural Resources and Environment, Department of Environmental Quality Promotion, Department of Local Administration, Ministry of Industry, National Science and Technology Development Agency, Thailand Board of Investment, Local Government Units and Municipal Authorities, Private Sector and Industry Associations)	M	2	M

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SUPPLEMENTARY INFORMATION SECTION 1
Detailed Methods

The dynamic Integrated Economic-Environmental Model (IEEM) linked with spatial Land Use Land Cover (LULC) change and Ecosystem Services Modeling (IEEM+ESM) approach was applied in this study, which is a cutting-edge analytical framework that incorporates feedback between changes in Ecosystem Services (ES) and the economy while maintaining consistency with a country's System of National Accounts. The three main models comprising IEEM+ESM — namely IEEM, the LULC change model, and the ES models— and how they interact are discussed in turn.

An Integrated Economic-Environmental Model (IEEM) for Thailand

IEEM+ESM is an economy-wide, decision-making framework for evidence-based public policy and investment design. The framework is being applied by multilateral institutions and government institutions including Ministries of Finance and Central Banks in future-looking analysis of public policy and investment. IEEM+ESM models have been developed and applied in over 30 countries to answer hundreds of questions of public policy and investment, including analysis of the complex challenges associated with climate change, the Sustainable Development Goals and Green Growth Strategies, and across economic sectors including energy, infrastructure, agriculture and tourism. Figure SI 1 presents the latest IEEM model coverage across the globe.

Figure SI1. IEEM+ESM countries indicated in green

Source: Authors' own elaboration based on above cited data.

The value-added of IEEM includes: (i) the model's integration of detailed environmental information through the United Nations System of Environmental-Economic Accounting (SEEA; United Nations et al., 2014) to represent the economy and the environment in a comprehensive and inter-connected way, all consistent with the System of National Accounts (European Commission et al., 2009); (ii) the model's generation of indicators demanded by policy makers including Gross Domestic Product (GDP), employment, and poverty, as well as metrics of wealth, sustainability, natural capital stocks, and ES supply. The metric of wealth used is a variation of adjusted net savings or genuine savings (Hamilton, 1999; Hamilton and Clemens, 1999) in which net national savings is adjusted for changes in natural capital stocks and environmental damage. GDP, on the other hand, lacks the value of changes in natural capital stocks and environmental damage. Wealth metrics are necessary to inform policies aimed at sustainable economic development rather than once-off, short-run economic growth at the expense of a country's natural capital asset base (Banerjee et al., 2021b; Dasgupta, 2021; Lange et al., 2018; Polasky et al., 2015; Stiglitz et al., 2010, 2009; UNEP, 2018); (iii) IEEM's environmental modeling modules that capture the specific dynamics of natural capital-based sectors while IEEM's linkage with spatial ES modeling enables estimation of impacts on the future flow of market and non-market ES.

At its core, IEEM is a single-country recursive dynamic Computable General Equilibrium (CGE) model (Burfisher, 2021; Dervis et al., 1982; Dixon and Jorgenson, 2012; Kehoe, 2005; Shoven and Whalley, 1992). CGE models are among the most well-documented class of models in the literature over the last four decades, outlining the theory, methods, strengths, and limitations of the approach (Burfisher, 2021, 2017; Cicowiez and Lofgren, 2017; Dervis et al., 1982; Dixon and Jorgenson, 2012; Kehoe, 2005; Shoven and Whalley, 1992).

Three key documents provide detailed technical information for IEEM: (i) IEEM's mathematical structure is documented in Banerjee and Cicowiez (2020); (ii) IEEM's database is an environmentally extended Social Accounting Matrix (SAM) described in Banerjee et al. (2019b), and, (iii) a user guide for IEEM, applicable to any country with the corresponding database, is available in Banerjee and Cicowiez (2019). With the IEEM model's theory maintained separately from a country application's data and database, these three documents provide the relevant technical detail for any IEEM country application.

The results from simulations with IEEM provide a comprehensive and consistent view of the economy and its evolution over time, including linkages between primary factors; production and the income it generates; households; the government (its policies and budget), and the balance of payments. In terms of theoretical pedigree, IEEM for Thailand can be characterized as a dynamic extension of standard comparative-static single-country CGE models for developing countries in the tradition of Dervis et al. (1982), Lofgren et al. (2002) and Robinson et al. (1999). In recent years, models belonging to this class have been widely used in applied development policy research.

CGE models, in contrast to partial equilibrium approaches, consider all sectors in an economy simultaneously and take consistent account of economy-wide resource constraints, inter-sectoral intermediate input-output linkages, and interactions between markets for goods and services on the one hand, and primary factor markets including labor markets on the other. CGE models such as IEEM simulate the full circular flow of income in an economy, from income generation from production to the primary distribution of that income to workers, owners of productive capital, and recipients of the proceeds from natural capital endowments. Income is used for consumption and investment and its redistribution may be achieved through taxes and transfers.

In the current application to Thailand, the starting point for the construction of the IEEM database, a Social Accounting Matrix (SAM) is Thailand's most recent (2012) Supply and Use Tables[6] and 2019 macro-economic data from the Office of the National Economic and Social Development Council, government budget data from the Bureau of the Budget, and balance of payment data from the International Monetary Fund. Thailand's SAM distinguishes 26 production activities and 26 commodities or products; eight primary production factors including labor factors, private capital, government capital; five natural resources (agricultural land and mineral stocks); and one household category (Table SI.1.).

Table SI1. Accounts in the 2019 Social Accounting Matrix for Thailand

Category	Item
Sectors (activities [26] and commodities [26])	Agriculture: crops; livestock Other primary: forestry; fishing; mining Manufacturing: food industry; textiles and wearing apparel; wood and paper; chemicals; rubber and plastic; non-metallic mineral prod; metals and metal prod; machinery and equipment; vehicles; other manufacturing Other industry: electricity, gas and water; construction Services: trade; hotels and restaurants; transport; business services; public administration; education; education and health; recreation; other services
Factors (8)	Labor Capital, private Capitall, goverment Land: crops, livestock, forestry Fishing Mining
Institutions (4)*	Households Government Rest of the World International Tourists
Taxes (2)	Tax, indirect Tax, direct
Distribution margins (3)	Trade and transport margins, domestic Trade and transport margins, imports Trade and transport margins, exports
Investment (3)	Investment, private Investment, government Investment, change in inventories

*The institutional capital accounts are for domestic non-government (aggregate of households and enterprises), government and rest of the world.
Source: Authors' elaboration.

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[6] Published in the Asian Development Bank Data Library: https://data.adb.org/dataset/supply-and-use-tables-Thailand

The numerical calibration process for IEEM involves the determination of the initial model parameters in such a way that the equilibrium solution for the 2019 benchmark year exactly replicates the 2019 benchmark SAM. The values for the sectoral elasticities of factor substitution, the Armington elasticities (i.e., the elasticities of substitution between imports and domestically produced output by commodity), the Constant Elasticity of Transformation (CET) elasticities (i.e., the elasticities of transformation between exports and domestic sales), and the income elasticities of household demand are informed by available econometric evidence from secondary sources presented in Aguiar et al. (2019), Muhammad et al. (2011) and Sadoulet & de Janvry (1995). In summary, the elasticities of factor substitution are in the range of 0.20-0.95, the Armington and CET elasticities are both in the range of 0.9-2.0, and the income elasticities of household demand are in the range 0.72-1.52.

IEEM may be used directly to estimate public policy and investment impacts on material ES (IPBES, 2019), also referred to as provisioning ES (European Environment Agency, 2018; Haines-Young and Potschin, 2012), most of which have a market price. With some database customization, IEEM may also be used to directly estimate impacts on cultural and recreational ES including tourism and recreation. To enable estimation of impacts on non-material ES, also known as regulating ES, which generally do not have a market price, we link IEEM with spatial LULC change and ES modeling. In linking IEEM with spatial modeling, we can estimate impacts on regulating services that are driven by localized (national level) LULC change such as erosion mitigation, crop pollination, water regulation, and water purification services. The bridge between IEEM and the spatial ES modeling is made through the spatial allocation of IEEM-projected demand for land using a LULC change model as described in the section that follows.

Land Use Land Cover Change Modeling

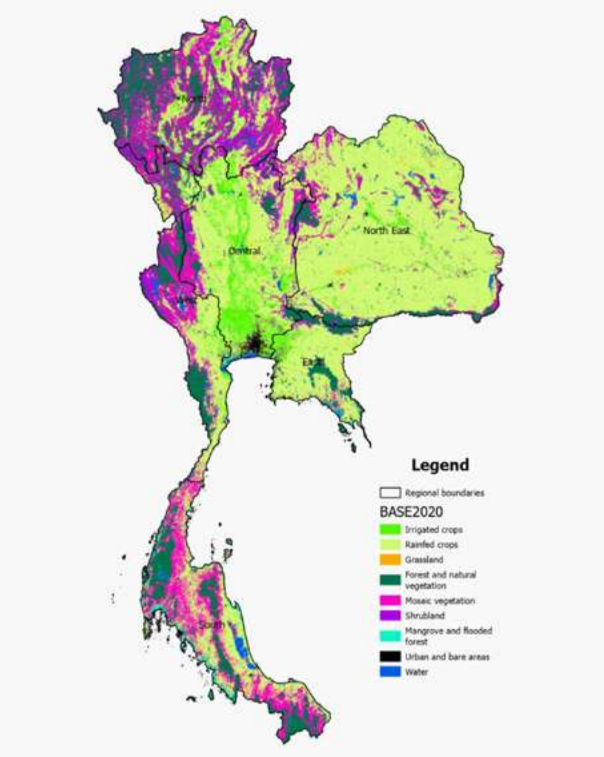
LULC change modeling is the necessary bridge between IEEM and spatial ES modeling. We use the CLUE (Conversion of Land Use and its Effects; Verburg et al., 2008, 1999; Verburg and Overmars, 2009a) modeling framework to spatially allocate LULC change using empirically quantified relationships between land use and location factors, in combination with the dynamic modeling of competition between land use types. CLUE is among the most widely used spatial LULC change models and has been applied at different scales across the globe (Rakotoarinia et al., 2023).

The version of the CLUE model family used is the Dynamic CLUE (Dyna-CLUE) model, which is appropriate for smaller regional extents compared with global LULC change modeling (Veldkamp and Verburg, 2004; Verburg et al., 2021, 2002; Verburg and Overmars, 2009b). IEEM demand for land is spatially allocated across a grid with the LULC change model to generate baseline and scenario-based mapped projections of LULC. The maps are the main variable of change used in the ES modeling, with most other parameters held constant.

The Dyna-CLUE model is sub-divided into two distinct modules: a non-spatial demand module populated with IEEM-derived demand for land, and a spatially explicit allocation procedure. The allocation procedure determines the probability of occurrence of each LULC class for each pixel as described below (suitability analysis). The results from the demand module specify, on an annual basis, the area covered by the different land use types, which is a direct input to the allocation module. Annual demands for forest, rain-fed crops, and grazing areas (and/or other LULC classes, depending on the specific application) are generated by IEEM. In an intermediate step to the allocation of demand for land, Dyna-CLUE calculates suitability maps for each land use type that reflect the probability of each land-use class occurring for each pixel. This suitability analysis is performed as a binomial logit stepwise regression for each land use and set of explanatory variables (Verburg et al., 2021).

The IEEM-Enhanced Dyna-CLUE LULC change model was calibrated for this application. The 2020 LULC map developed through the European Space Agency's Climate Change Initiative (Defourny et al., 2019) was used as the base map. This base map was selected based on the relevance of the LULC classes that it presents (27 classes), its long-time series (1992 to present with a few year delay), its recent base year (2020), and its spatial resolution (300 meters). We reclassified the base map to nine LULC classes to meet the needs of this application. The reclassified map is shown in SI 2 and the initial area in each LULC class is shown in SI 2.

Figure SI2. Reclassified base Land Use Land Cover (LULC) Map for 2020



Source: Reclassified based on European Space Agency (ESA) Climate Change Initiative (CCI) 2020 Land Use Land Cover (LULC) Map.

Table SI2. Reclassified Land Use Land Cover (LULC) classes and areas

Land Use Land Cover Class	Hectares
Irrigated crops	2,967,525
Rainfed crops	27,688,075
Grassland	183,700
Forest and natural vegetation	8,250,500
Mosaic vegetation	8,594,400
Shrubland	2,156,225
Mangrove and flooded forest	378,775
Urban and bare areas	436,875
Water	958,350
Total	**51,614,425**

Source: Calculations made based on European Space Agency (ESA) Climate Change Initiative (CCI) 2020 Land Use Land Cover (LULC) Map.

Ecosystem Services Modeling

The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) suite of models (Natural Capital Project, 2023b) was used in the IEEM+ESM workflow to calculate scenario-based, spatially-explicit changes in ES supply. The InVEST models are open source, well documented, and the most widely used set of tools for ES modeling globally. InVEST combines LULC maps and biophysical information to calculate ES. In this study, six ES models were parameterized based on both global and national data sources, namely: the sediment delivery ratio model used to calculate the Revised Universal Soil Loss Equation; the carbon storage model used to calculate carbon storage and carbon sequestration potential; the annual water yield model to calculate water supply; the nutrient delivery ratio model to calculate the amount of nutrients transported to streams; the crop pollination model to calculate an index of pollinator abundance; and, the coastal vulnerability model to calculate an index of exposure to erosion and inundation during storm events.[7]

The main variable of change in the ES modeling is the scenario-driven LULC projections generated with the Dyna-CLUE model. New LULC maps for each scenario and time period are used in each InVEST model run for each of the five InVEST models. Note the coastal vulnerability model does not require LULC as an input and thus is not discussed in the section that follows. Scenario-driven changes in ES supply in any given year are calculated as differences between ES in the scenario for year t and for the baseline scenario for that same year. For ease of interpretation and analysis, results were summarized as a percent difference from baseline for each of Thailand's six regions.

Model Integration and Interaction: The Dynamic IEEM+ESM Approach

In the basic IEEM+ESM workflow, scenarios are implemented in IEEM and impacts on economic indicators are reported. As described above, IEEM generates a projection of demand for land that is spatially allocated with the LULC change model. The five ES models are run with the LULC change maps generated for the baseline initial year and final year as well as for each scenario. The difference between ES supply in each scenario and the baseline case in the final time period provides the scenario-based impact on the five ES. This information alone, reported in biophysical units, is valuable for shedding light on trade-offs between economic, environmental, and social outcomes.

Changes in ES supply affect the economy through various mechanisms. Some ES impacts are determined in IEEM without any additional spatial or ES modeling. This pertains specifically to provisioning ES that have existing markets. Following the Common International Classification of Ecosystem Services (European Environment Agency, 2018; Haines-Young and Potschin, 2012), these ES include: food, potable water supplied by a utility company, fiber/biomass, and mineral and non-mineral subsoil extracts. With additional SAM database customization, cultural and recreational ES values are also estimated through IEEM implementation (Banerjee et al., 2018).

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[7] Note that the implementation of the coastal vulnerability model is preliminary since there is a lack of data related to wave heights and wind speed and direction in proximity to Thailand's mainland.

The basic workflow does not, however, generate economic values for those ES, mostly regulating ES, that do not have a market price. The InVEST models on their own also do not generate these values. While it is possible to estimate the economic value of changes in ES flows using ES values obtained from stated preference, benefits transfer, and other environmental economic methods, in this study we implemented the dynamic IEEM+ESM approach that captures the impacts of policies on regulating ES that do not have a market price. IEEM+ESM incorporates dynamic feedbacks between natural capital, ES, and the economic system (Banerjee et al., 2020; Banerjee et al., 2019a; Banerjee et al., 2020b) enabling estimation of the contribution of regulating ES to economic indicators.

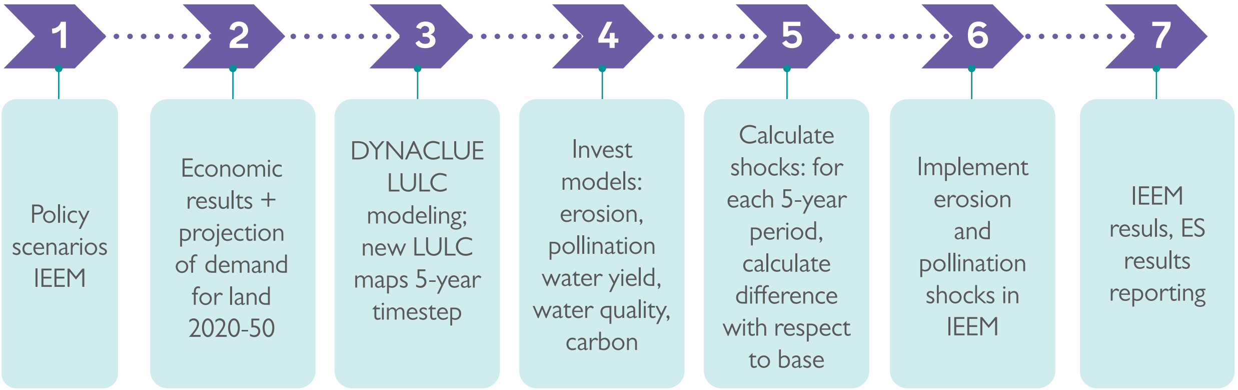
These regulating ES include both abiotic and biotic services such as: hydrological regulation including flood control and coastal protection, regulation of soil processes, wind and fire protection, climate and air quality regulation, pest and disease control, and pollinator activity. To integrate these ES in the dynamic IEEM+ESM framework, the ES of interest is identified and a transmission pathway to the economy then is established in quantitative terms. In this study, we focus on integration of soil erosion mitigation and crop pollination ES in the dynamic framework, though we also estimate impacts on the economic value of cultural and recreational and provisioning ES and impacts on the remaining four regulating ES (water regulation, water purification, carbon storage, and coastal vulnerability) in biophysical units.

Specifically, we related changes in soil erosion mitigation ES (Borrelli et al., 2017; Panagos et al., 2018, 2015; Pimentel, 2006; Pimentel et al., 1995) and crop pollination ES (Bauer and Sue Wing, 2016; Garibaldi et al., 2016; Johnson et al., 2021; Kennedy et al., 2013; Klein et al., 2007) to agricultural productivity. Additional transmission pathways (though not considered here) could be specified; for example, increased soil erosion and nutrient run-off affect water quality, which can have implications for water treatment costs, human health, and tourism values (Aguilera et al., 2018; O Banerjee et al., 2019; Keeler et al., 2012; O'Neil et al., 2012; Paerl and Huisman, 2008; STAC, 2013).

The dynamic IEEM+ESM approach has three important features that advance integrated economic-environmental methods published elsewhere: (i) by accounting for changes in ES flows throughout the analytical period, agents in IEEM adjust their behavior according to these changes in ES flows; (ii) the approach maintains consistency with a country's National Accounting System, which enhances its credibility with country institutions including Ministries of Finance and Central Banks that are often responsible for developing and maintaining their country's System of National Accounts; and, (iii) the economic value of regulating ES is calculated endogenously in the IEEM+ESM framework.

In this study, demand for land is exogenous and defined entirely by the scenarios themselves. Where demand for land is endogenous, price in IEEM is the equilibrating mechanism that brings supply and demand into balance. In this workflow presented in Figure SI 3, Dyna-CLUE is implemented to spatially allocate demand for land. Using the LULC maps produced through the LULC modeling, the ES models of interest (the sediment delivery ratio model and crop pollination model in this case that are used to calculate soil erosion mitigation ES and pollinator abundance, respectively) are run in periodic time steps (five-year periods in this study) for the entire analytical period.[8]

Figure SI3. Overview of the dynamic IEEM+ESM workflow applied to Thailand



Source: Authors' own elaboration.

In the case of the sediment delivery ratio model, this model calculates the soil loss per pixel across the country (tons/pixel). In the case of the crop pollination model, pollinator abundance is calculated as an index of pollinator abundance for each pixel. The scenario impact on ES supply is calculated as the difference between the scenario ES map in year t+5 and the baseline ES map in the year t+5 using a raster calculator in a Geographic Information Systems (GIS) software package. Since ES impacts are calculated on a five-year basis, the change in ES between five-year time steps is calculated by simple linear interpolation. To link the change in soil erosion mitigation and crop pollination ES back to the economy, economic shocks for each ES are calculated to account for the change in future ES supply.

We estimated the impact of changes in erosion on agricultural productivity based on a survey of the literature. We establish a threshold after which erosion is considered to have a measurable effect on agricultural productivity. Following Panagos et al. (2018) and our survey of the literature, this threshold is set to a level of erosion greater than 11 tons per hectare per year. In this approach, first we identify the area by Thai region exhibiting erosion of greater than 11 tons/ha, using zonal statistics and the raster calculator in a GIS software package, for both the baseline and each scenario. If the area of erosion greater than 11 tons/ha is larger in the policy scenario compared with the baseline, this indicates that erosion has increased as a result of the policies implemented in the scenario. If the area of erosion greater than 11 tons/ha is smaller in the scenario compared with the baseline, this indicates that erosion has decreased as a result of the policies implemented in the scenario.

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[8] Note that when demand for land is exogenously determined, as is the case in this study where the scenarios define the demand for land, the LULC change model and the ES models are run iteratively to calculate changes in ES and the economic shocks described below. Iteration between all three models (IEEM, the LULC change model and the ES models) is required where there is endogeneity in demand for land (for example, see: Banerjee, Cicowiez, et al. (2020b) and Banerjee, Cicowiez, Malek, et al. (2022)).

Based on Panagos et al. (2018) and our survey of the literature, we relate the presence of erosion greater than 11 tons/ha to a reduction in agricultural productivity of 8 percent. This 8 percent is applied from the base year to 2050. In a more pessimistic scenario, we use a value of 16 percent.

To create feedback between changes in ES and IEEM, we apply equation 1 to each scenario:

$$LPL_r = \frac{SER_r}{TAA_r} \cdot 0.08 \qquad \textit{equation 1}$$

Where:

- LPL_r is the land productivity loss by subscript region r of Thailand;
- SER_r is the agricultural land area (hectares) subject to erosion >11t/ha/year in each region;
- TAA_r is the total agricultural area, both crop and livestock, by region and;
- **0.08** is the agricultural productivity shock.

In the case of crop pollination ES, the dependence of specific agricultural crops and the crop yield impacts related to the presence or absence of pollinators was based on a seminal paper by Klein et al. (2007). This paper provides the most comprehensive review of studies that associate crop dependence on pollinators and yield. Due to the high level of disaggregation in crop types required for this exercise, data from FAOSTAT — the UN Food and Agriculture Organization's statistics division — on specific crops for Thailand were used in conjunction with the IEEM database.

With crop output value as the variable of interest, Thailand's crop output in the base year was mapped to the crops presented in Klein et al. (2007). Note that some of the crops present in Klein et al. (2007) were not produced in Thailand and some crops produced in Thailand including staple crops such as wheat, rice, and corn are not pollinator dependent. Pollinator dependent crops are, however, important for human nutrition, and deficiencies in nutrition have been directly associated with pollinator decline (Chaplin-Kramer et al., 2019; Ellis et al., 2015; Smith et al., 2022). Analysis of this data shows that 23 percent of the crop output in Thailand is to some degree pollinator dependent. An economic shock to describe the relationship between crop pollinator abundance and crop yield was calculated as described in equation 2.

$$CPC_r = D_r \cdot (A_r \cdot Y_{(r,vh)} \cdot V_{(r,vh)} \cdot W_{(r,vh)} + A_r \cdot Y_{(r,h)} \cdot V_{(r,h)} \cdot W_{(r,h)} + A_r \cdot Y_{(r,m)} \cdot V_{(r,m)} \cdot W_{(r,m)} + A_r \cdot Y_{(r,l)} \cdot V_{rl} \cdot W_{(r,l)}) \qquad \textit{equation 2}$$

Where:

- D_r is a pollinator adjustment factor representing current pollinator abundance relative to full potential abundance.
- CPC_r is the crop productivity impact for subscript region ***r*** of Thailand;
- A_r is pollinator abundance in subscript region ***r*** of Thailand;
- $Y_{(r,vh)}$ is the yield impact in region ***r*** for very highly pollinator dependent crops (subscript ***vh***);
- $V_{(r,vh)}$ is the value of crop output in region ***r*** for very highly pollinator dependent crops

(subscript ***vh***);

- $W_{(r,vh)}$ is the weight of the value of very highly pollinator dependent crops (subscript ***vh***) in Thailand's total crop output value and;
- Subscripts ***h***, ***m*** and ***l*** refer to high, medium and low dependent pollinator crops.

Pollinator abundance is calculated based on the baseline and scenario-based LULC maps generated with Dyna-CLUE. The pollinator adjustment factor in the case of Thailand is based on Chaudhary and Chand (2017). Yield impacts are derived from Klein et al. (2007) and mapped to Thailand's crop output from FAOSTAT and the IEEM database. The crop output value and weights are calculated from FAOSTAT data. We implement *LPLr* and *CPCr* shocks in IEEM individually and simultaneously, which enables analysis of the individual contribution of erosion mitigation and crop pollination ES to economic outcomes. The IEEM+ESM approach enables estimation of the marginal value of regulating ES that generally do not have a market price. At the time of publication, the dynamic IEEM+ESM workflow is the only modeling framework in the peer-reviewed literature that integrates dynamic feedback between changes in ES and the economy in this way.

SUPPLEMENTARY INFORMATION SECTION 2

Full Scenario Description

What follows is a complete description of the scenarios implemented in IEEM.

Baseline: This is the business-as-usual scenario that is used as the counterfactual reference scenario to which all other scenarios are compared. It presents the future trajectory of Thailand's economy, projected until 2050, in the absence of any new large public policies and investments and without further acceleration in the degradation of the natural capital base. The rate of deforestation is based on (TEIF, 2021) and is calculated as 0.37 percent annually. It is assumed that 50 percent of the area deforested is converted to productive cropland and the remaining 50 percent is assumed to be degraded, unproductive, and unused. The baseline scenario includes climate change impacts for current policies, estimated through a damage function approach. These impacts include damages and losses related to floods and cyclones, reduced labor and land productivity for agriculture, reduced construction sector labor productivity, tourism demand, and sea level rise as estimated in Markandya (2023).

DEGRADE: Upon the baseline counterfactual, the first set of scenarios (DEGRADE) will represent some of the main drivers of degradation discussed in the introduction. The comparison between the baseline and DEGRADE reveals the economic, wealth, natural capital, and ES costs of policy inaction. DEGRADE is comprised of the following sub-scenarios:

DEFOR: This sub-scenario represents an accelerated rate of deforestation with respect to the baseline rate of deforestation. The projected rate of deforestation follows that of Global Forest Watch data that is calculated as 0.5804 percent per year (Hansen et al., 2013; Harris et al., 2021). Fifty percent of deforested land is assumed to be converted to productive cropland and the other 50 percent is assumed to be degraded, unproductive, and unused.

DEFOR2: This sub-scenario represents an accelerated rate of deforestation with respect to the DEFOR rate of deforestation. In this sub-scenario, an exponential decay function is applied to the rate of deforestation in which the standing stock of forest left in 2050 is approximately 5.425 million ha, which approximates the size of Thailand's protected forest area. All new deforested areas are assumed to be degraded, unproductive, and unused in this sub-scenario.

FLOOD: This sub-scenario simulates coastal and inland flooding due to storms and cyclones and its damage to infrastructure. A damage function approach was used that projects damage from these phenomena for Relative Concentration Pathways (RCP) 4.5 and RCP8.5 projections. The 90th percentile of damages arising from flooding was used in this scenario (Markandya, 2023). The distribution of economic impacts across Thailand's economy followed that of the 2011 flood (World Bank, 2012).

CATFLOOD: This sub-scenario represents increasing intensity and frequency of storms leading to extreme coastal and inland flooding. Thailand's 2011 flood was considered a one in 50-year event. In this sub-scenario, we simulate two of these storm events occurring within the modeling horizon to 2050. The year in which these storms occur was chosen as a random number draw, resulting in these catastrophic floods occurring in years 2029 and 2047. The severity of the economic impact of the flood in this sub-scenario was assumed to be double that of the 2011 flood. The distribution of economic impacts across Thailand's economy followed that of the 2011 flood (World Bank, 2012).

CLIMATE_AGRI: This sub-scenario simulates the impact of projected climate change on:

(i) agricultural land productivity. We apply a damage function approach in which damages from climate change impacts on land productivity for RCP4.5 and RCP8.5 were estimated in Markandya (2023) and applied in this sub-scenario; and,

(ii) agricultural labor productivity. We apply a damage function approach in which damages from climate change impacts on agricultural labor for RCP4.5 and RCP8.5 were estimated in Markandya (2023) and applied in this sub-scenario.

LABPROD: This sub-scenario simulates the impact of projected climate change on construction sector labor productivity. We apply a damage function approach in which damages from climate change impacts on construction sector labor productivity for RCP4.5 and RCP8.5 were estimated in Markandya (2023) and applied in this sub-scenario.

TOUR: This sub-scenario simulates the impact of projected climate change — specifically, temperature rise — on foreign tourism demand in terms of a reduction in the number of tourist arrivals and their average expenditure. We apply a damage function approach in which damages from climate change impacts on tourism demand for RCP4.5 and RCP8.5 were estimated in Markandya (2023) and applied in this sub-scenario.

SEALEVEL: This sub-scenario simulates the impact of sea level rise on coastal infrastructure. We apply a damage function approach in which damages from climate change impacts on sea level rise for RCP4.5 and RCP8.5 were estimated in Markandya (2023) and applied in this sub-scenario.

ERODE: This sub-scenario models the effect of LULC change and deforestation on soil erosion and its resulting impact on agricultural productivity following Banerjee et al. (2023) and Banerjee & Cicowiez (2022).

POLLEN: This sub-scenario models the effect of LULC and deforestation on crop pollination and its resulting impact on agricultural productivity following Banerjee et al. (2023) and Banerjee & Cicowiez (2022).

Note that RCP4.5 and RCP8.5 pathways were used in the estimation of the damage functions for the following scenarios: FLOOD, CLIMATE_AGRI, LABPROD, SEALEVEL, TOUR and DEGRADE. The names of the scenarios that use the RCP4.5 projections terminate with _OPT, and the names of the scenarios that use the RCP8.5 projections terminate with _PES+.

POLICY: Contrasting with the DEGRADE scenarios, the policy and investment (POLICY) scenario simulates the implementation of climate change mitigation and adaptation strategies. The comparison of POLICY and DEGRADE shows the economic benefits of investing in enhancing natural capital and resilience and contributing to economic recovery, as well as trade-offs that may exist between economic, social, and environmental outcomes. The POLICY scenario is comprised of the following sub-scenarios:

NODEFOR: This sub-scenario represents the elimination of deforestation with respect to the DEFOR scenario's rate of deforestation. Deforestation is reduced linearly beginning in 2024 until reaching zero new deforestation in 2037. The cost of avoiding deforestation was estimated as an annual reoccurring cost equivalent to US$5.82/ha/yr.[9]

REDFLOOD: This sub-scenario simulates measures to reduce the damages caused by coastal and inland flooding and cyclones through the implementation of early warning and monitoring systems as well as physical infrastructure to mitigate damage. This sub-scenario also assumes global cooperation, that all countries implement their NDCs, and that these NDCs are effective in mitigating climate change impacts related to increasing frequency and intensity of storms. These measures are assumed to be effective in offsetting 70 percent of the climate change impacts on agriculture as captured by the FLOOD and CATFLOOD sub-scenarios. The investment costs for transportation infrastructure were supplied by the World Bank. For RCP4.5, we use 75 percent of these investments in transportation infrastructure, and for RCP8.5, we use 100 percent of these costs. Investment costs for coastal protection, river protection, and Water, Sanitation and Hygiene (WASH) were supplied by the World Bank. For this sub-scenario, we use 100 percent of river protection costs and WASH costs and 25 percent of coastal protection costs. For RCP4.5 the "best" investment scenario was used, while for RCP8.5, the "max'"investment scenario was used.

REDCLIMATE_AGRI: This sub-scenario simulates measures to adapt to projected climate change and its impact on agricultural land and agricultural labor productivity. These measures are assumed to be effective in offsetting 70 percent of the climate change impacts on agriculture as captured by the CLIMATE_AGRI sub-scenario. Investments in adapting to climate change include investment in irrigation and climate-smart agriculture. Investments in irrigation infrastructure were supplied by the World Bank. For RCP4.5, the "best" investment scenario was used, while for RCP8.5, the "max" scenario was used. Investments in climate adapted agriculture follow the estimates presented in Khatri-Chhetri et al. (2021).

REDSEALEVEL: This sub-scenario assumes global cooperation, that all countries implement their NDCs, and that these NDCs are effective in mitigating and adapting to sea-level rise. Investments in adapting to sea level rise were supplied by the World Bank. We used 75 percent of the coastal protection investments presented in the data and the "best" investment scenario for RCP4.5 and "max" investment scenario for RCP8.5. These measures are assumed to be

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[9] This cost is based on the Cambodia CCDR and specifically on the (REDD+ Task Force Secretariat, 2020). For reference, the cost of fire protection in Cambodia between 2013 and 2022 was on average US$8.6 million/year which equates to US$1.89/ha/yr, considering a standing forest stock of 16,255,595 (see email of September 27 and 29, 2023). This value is low; as a point of comparison, in Brazil's CCDR, we used a value of US$538.70/yr/ha (Consultant for the World Bank, 2022).

effective in offsetting 70 percent of the sea level rise impacts as captured by the SEALEVEL sub-scenario.

INCTOUR: This sub-scenario assumes global cooperation, that all countries implement their NDCs, and that these NDCs are effective in mitigating and adapting to climate change impacts on temperature and its effect on foreign tourism demand. Measures implemented in this sub-scenario were assumed to be effective in offsetting climate change impacts on tourism by 70 percent. Data was not available to support the investments required to adapt to climate change impacts on tourism , so the impacts of this scenario should not be considered in isolation. Instead, its relevance is its contribution to the overall POLICY scenario.

AFFOR: This sub-scenario simulates the provisions in the National Development Strategy for planting of 1,806,400 ha of forest plantations (Kingdom of Thailand, 2019; Ministry of Natural Resources and Environment, 2019). To meet the target area by 2037, 129,029 ha per year are planted, with all of these newly planted forests (100 percent) used for commercial forestry purposes. The cost of afforestation, including establishment and early maintenance costs, was estimated as $200/ha and was based on the Thai government budget for similar activities in the past. It is assumed that the trees planted are harvestable by year 10 and reach maximum carbon storage at 18 years of age.

RESTORE: This sub-scenario simulates the provisions in the National Development Strategy for restoring and increasing the area of natural forests by 2,558,400 ha (Kingdom of Thailand, 2019; Ministry of Natural Resources and Environment, 2019). To meet the target area by 2037, 182,743 ha per year would be planted. Twenty percent of these newly planted forests will be used for commercial forestry purposes. The cost of restoration is assumed to be half that of afforestation and thus equal to $100/ha. It is assumed that the trees planted are harvestable by year 10 and reach maximum carbon storage at 15 years of age.

REDERODE: This sub-scenario simulates the impact of forest restoration and eliminating deforestation and afforestation (RESTORE, REDEFOR, and AFFOR, respectively) on erosion mitigation ES.

REDPOLLEN: This sub-scenario simulates the impact of forest restoration and eliminating deforestation and afforestation (RESTORE, REDEFOR, and AFFOR, respectively) on crop pollination ES.

Note that RCP4.5 and RCP 8.5 pathways were used in the estimation of the damage functions for the following sub-scenarios: REDFLOOD, REDCLIMATE_AGRI, RELABPROD, REDSEALEVEL, INCTOUR, and POLICY. The names of the scenarios that use the RCP4.5 projections terminate with _OPT and the names of the scenarios that use the RCP8.5 projections terminate with _PES+.

SUPPLEMENTARY INFORMATION SECTION 3

Detailed IEEM+ESM Results

Table SI3. Macroeconomic results in millions of USD

	DEFOR	DEFOR2	FLOOD_OPT	FLOOD_PES	CATFLOOD	CLIMATE_AGRI_OPT	CLIMATE_AGRI_PES	CLIMATE_AGRI_PES+	LABPROD_OPT	LABPROD_PES	LABPROD_PES+
GDP	-209	428	102	-525	-34,901	-1,382	-4,123	-7,872	37	-572	-1,152
Cumulative GDP	-952	2,027	1,444	-5,654	-412,791	-15,352	-49,121	-90,807	1,272	-6,506	-13,096
Wealth	-396	-946	19	-92	-6,085	994	1,588	1,305	6	-126	-254
Cumulative wealth	-5,647	-19,317	247	-958	-70,407	16,708	26,886	22,893	264	-1,505	-3,029
Private consumption	3	-11	75	-387	-25,914	-1,407	-4,381	-8,933	34	-352	-709
Private investment	-221	453	33	-171	-11,368	91	322	955	5	-254	-511
Exports	-447	913	95	-493	-32,682	-1,808	-3,631	-4,218	32	-483	-973
Imports	-412	843	89	-463	-30,749	922	1,330	1,043	29	-447	-900

Source: IEEM+ESM results.

Table SI4. Macroeconomic results in millions of USD, continued

	SEALEVEL_OPT	SEALEVEL_PES	SEALEVEL_PES+	TOUR_OPT	TOUR_PES	TOUR_PES+	ERODE_PES	ERODE_PES+	POLLEN_PES	POLLEN_PES+	DEGRADE_OPT	DEGRADE_PES	DEGRADE_PES+
GDP	0	-613	-1,225	-280	-463	-900	-46	-759	-102	-551	-36,442	-41,864	-46,878
Cumulative GDP	0	-9,818	-19,657	-588	-1,911	-3,783	-712	-9,871	-906	-7,508	-423,101	-483,895	-553,708
Wealth	0	-38	-73	2	-31	-72	-3	-52	-8	-37	-6,564	-8,414	-6,888
Cumulative wealth	0	-808	-1,598	1,140	1,220	2,166	-58	-822	-77	-627	-75,420	-102,743	-80,530
Private consumption	0	-762	-1,533	-300	-460	-845	-57	-920	-119	-671	-27,392	-32,177	-39,652
Private investment	0	141	288	-648	-829	-1,634	11	149	15	111	-11,999	-12,907	-11,287
Exports	0	-17	-27	-1,041	-1,389	-2,797	-1	-61	-15	-40	-34,314	-37,822	-37,279
Imports	0	27	61	-1,426	-1,833	-3,596	2	-9	-9	-1	-32,551	-35,670	-35,136

Source: IEEM+ESM results.

Table SI5. Macroeconomic results in millions of USD, continued

	NODEFOR	REDFLOOD_OPT	REDFLOOD_PES	REDCLIMATE_AGRI_OPT	REDCLIMATE_AGRI_PES	REDCLIMATE_AGRI_PES+	REDSEALEVEL_OPT	REDSEALEVEL_PES	REDSEALEVEL_PES+
GDP	44	-7,464	-10,655	-341	-1,101	-2,208	195	-39	-223
Cumulative GDP	-292	-80,425	-131,328	-3,239	-12,249	-24,557	2,678	-1,179	-4,123
Wealth	677	-1,991	2,602	-26	-101	-199	348	533	522
Cumulative wealth	7,770	-24,680	50,434	-243	-1,277	-2,535	5,640	8,591	8,347
Private consumption	-113	-5,263	-7,349	-403	-1,260	-2,543	219	-24	-252
Private investment	156	-2,580	-3,594	56	138	286	38	60	102
Exports	277	-23,013	-19,710	-43	-216	-422	-2,053	-2,330	-2,336
Imports	253	-4,149	-3,837	-20	-136	-262	844	1,020	1,028

Source: IEEM+ESM results.

Table SI6. Macroeconomic results in millions of USD, continued

	INCTOUR_OPT	INCTOUR_PES	INCTOUR_PES+	AFFOR	RESTORE	REDERODE_PES	REDPOLLEN_PES	POLICY_OPT	POLICY_PES	POLICY_PES+
GDP	-85	-142	-281	223	58	29	1,011	-7,658	-11,486	-14,548
Cumulative GDP	-176	-579	-1,153	12,111	3,757	285	17,749	-80,056	-134,175	-174,902
Wealth	1	-8	-17	106	42	2	64	-1,649	2,977	2,669
Cumulative wealth	357	395	765	4,711	1,667	24	1,507	-18,238	58,666	54,490
Private consumption	-95	-146	-285	-374	-131	34	1,251	-5,515	-7,857	-11,143
Private investment	-196	-251	-500	410	138	-4	-235	-2,674	-4,155	-4,217
Exports	-311	-415	-831	-433	-151	4	20	-25,383	-23,140	-24,324
Imports	-432	-558	-1,109	-364	-126	2	-54	-3,721	-4,024	-5,129

Source: IEEM+ESM results.

Table SI7. Macroeconomic results expressed as average growth rates over simulation period as percentage point difference from the baseline

	INCTOUR_OPT	INCTOUR_PES	INCTOUR_PES+	AFFOR
GDP	-85	-142	-281	223
GDP in 2050 with respect to BASE	-176	-579	-1,153	12,111
Wealth	1	-8	-17	106
Wealth in 2050 with respect to BASE	357	395	765	4,711
Private consumption	-95	-146	-285	-374
Private investment	-196	-251	-500	410
Exports	-311	-415	-831	-433
Imports	-432	-558	-1,109	-364

Source: IEEM+ESM results.

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